FORECASTING MEAN WEEKLY TEMPERATURE

BY STATISTICAL

SYNOPTIC CONSIDERATIONS

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Chung Pen Ho

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ABSTRACT

The scope of this thesis is to explore the relation between the weekly temperature anomaly at a test location and the general temperature anomaly pattern for the preceding week. Since the general pattern of circulation of a given week has a close relationship to that of the preceding week, and because the circulation pattern establishes the temperature anomaly pattern, it seems logical to infer that the temperature anomalies of two consecutive weeks are correlated. Moreover, as far as the properties of air mass are concerned, temperature is the more conservative property.

A test location is chosen and twenty to thirty other stations in an evenly scattered network around the United States are used in representing the temperature anomaly pattern during the preceding week. The weekly temperature distribution curves are then prepared for each station and a division into five ranges or categories is made. Contingency tables are then prepared showing the relation between the temperature anomalies of the test station and those of each network station during the preceding week. The mean number of matches are found and the standard deviation computed. The difference between the mean number of matches and actual number of matches divided by standard deviation gives the normal deviate. There exists a positive correlation if the normal deviate is positive and vice versa.

Using the calculated normal deviate at each of the network stations a contour map of this number is drawn. The result is interpreted on a synoptic basis. If some parts are inconsistent from the viewpoint of synoptic considerations, then those parts are disregarded as a forecasting basis.

In practical application, the relationships would be established for a large number of test or key stations and thus a weekly forecast temperature anomaly pattern could be made.

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INTRODUCTION

Many contributions have been made in an endeavor to throw light on the problem of long range weather forecasting. These contributions cover studies in a variety of fields such as solar radiation, atmospheric ozone content, ice and snow cover, ocean currents, mean circulation, analogues, periodicities and recurrences, statistical relations, etc. However, as forecast verifications indicate, the science of applied meteorology is still in a rather primitive stage. The handicap is that we do not have an exact knowledge of the process of heat exchange and dynamics of the atmospheric motion. Moreover, the complexity of the combination of various weather factors increases the difficulty of forecasting the future weather. Up to now there is no pure kinematic-hydromechanic approach in any of the known techniques of weather forecasting. It is believed that nearly all the methods developed are more or less based on probability basis, either directly or indirectly.

The best methods so far developed are weather type method and mean circulation method.

In the weather type method (1) the ideal type somewhat corresponds with the expected value of a certain population in the statistical point of view. When we make a forecast, we carefully pick out an analogue which matches well with current maps and follow it so that the probability of the forecasted weather deviating from the observed value is minimum. The same is true for mean circulation method (2). From the circulation indices calculated from the current weather data we try to figure by the trend what the indices of circulation will most probably be. The simple technique of forecasting an index is to consider its departure from normal and assume that the forthcoming change will be in the direction of the normal. No matter how sound our physical interpretation or empirical rules which are used in determining the trend, we can never expect that the forecast we made will verify one hundred per cent, because a trend is only a trend which tells us nothing more than a favorable probability.

The scope of this paper is to find the relation between temperature anomalies of two consecutive weeks. It is purely a statistical approach. Since the pattern of circulation of this week has a close relation with that of last week and change of temperature is due to change of circulation, it seems logical to say that the temperature anomalies of two consecutive weeks are highly correlated. Moreover, as far as the properties of air mass are concerned, temperature is more conservative than anything else. Choose a certain location as a principal station and twenty to thirty other stations evenly scattered around the United States. Classify the temperature anomalies into five categories as follows:

(a) Well above normal (10^{o}F. and above)

(b) Above normal (+ 4^{o}F. to + 9^{o}F.)

(c) Near normal (+ 3^{o}F. to - 3^{o}F.)

(d) Below normal (- 4^{o}F. to - 9^{o}F.)

(e) Far below normal (- 10^{o}F. and below)

Then use the matching technique to calculate the relation between the temperature anomaly at the principal station and the temperature anomaly during the preceding week at other stations. Using the calculated resultant normal deviate at each of the stations we draw the contour lines on a map. By the trend of those contour maps we can forecast the temperature anomaly at the principal station. We may choose different locations as the principal stations so that we can get the temperature anomalies around the whole United States. The contingency tables, normal deviates, etc., will be discussed in more detail later.

BRIEF STUDY OF TEMPERATURE ANOMALIES OVER NORTH AMERICA

The change of temperature day to day or week to week is mainly due to exchange of air masses. The distribution of different air masses frequenting different zones is shown in Fig. 1. The boundaries of these zones are arbitrarily chosen. Wherever the temperature anomaly goes down far below normal it is solely due to Pc outbreaks. As for the other four categories of temperature anomalies the causes are due to different combinations of air masses.

In zone I if the Pp high cell comes down over the Rocky Mountains of British Columbia the temperature anomaly will be below normal. If the Pp air comes in from the ocean with frontal activity the anomaly will be either above normal or well above normal, according to the activity of the associated fronts. Pp air combined with Pc will result either in above normal, near normal or below normal, depending upon ratio of the two air masses. Night radiational cooling will make the temperature of Pp air below normal. In case of overcast the night radiation is hindered and the temperature will be normal. Zone II is nearly the same as zone I except that the Tp air often comes into this area and makes the temperature above normal or well above normal, according to the activity of the associated fronts.

In zone III, Pp air with the aid of foehn action always makes the temperature well above normal. RPc whose path is confined to continent will make the temperature near normal or above normal. The combination of Pp, Pc and returning Pc may make the temperature above normal, below normal, or near normal according to the distribution of the duration of each air mass during the period. In zone IV the foehn effect on Pp is not so strong as in zone III, but anyhow Pp is associated with above normal temperatures. Sometimes the warm Tp or Pp with frontal activity runs down the slope of Rocky Mountains and causes the temperature to be well above normal. Tg air invades this area when and only when an active cyclone comes from zone II and is intensified in this area; in that case the anomaly will be well above. The condition of the combination of warm and cold air masses is the same as in other areas.

In zone V, Pc and RPc are predominant. Occasionally Pp air invades this area as in B and B_s (5) types. The returning Pc may either come from the south or from the east. Under continuous invasion of RPc or Pp into this area the temperature will become well above normal. It will be above, below or near the normal when the warm RPc and Pp are compensated by varying amounts of cold Pc. When the center of the Pc high locates over Ontario, the RPc is rather cold so the temperature will be near normal. Pa is an infrequent visitor to the United States, and its temperature is slightly warmer than Pc. In zone VI, if there is no snow cover on the ground, a continuous invasion of Tg, Ta or RPc will make the temperature well above normal. It will be above normal if there is snow cover on the ground. Sometimes a trapped Pc high stagnates over this area and will make the temperature either below or far below normal. Pp air in this area will make the temperature near normal. The condition of compensation of temperature of mixed air masses is the same as in other areas.

Since the frequency distribution of invasions of air masses in different areas are different, so are the frequencies of temperature anomalies. Table I gives the number of each category in 159 weeks for 25 stations.

Table I

Name of Station	T_{11}	T_{12}	T_{13}	T_{14}	T_{15}
Boston	9	29	76	33	12
Richmond	6	35	72	29	17
Charleston	7	32	71	32	17
Tampa	10	31	72	33	13
Pensacola	10	30	73	28	18
Shreveport	11	40	61	27	20
San Antonio	9	35	80	22	13
Nashville	11	33	63	29	23
Cleveland	13	44	54	29	19
Chicago	22	34	54	28	21
Sault St. Marie	21	45	55	24	14
Duluth	37	29	40	32	21
Topeka	30	33	46	30	20
North Platte	39	44	32	24	20
Bismarck	50	28	29	26	26
Havre	49	33	29	18	30
Lander	26	44	48	24	17
Pueblo	29	40	51	27	12
Amarillo	23	46	61	16	13
El Paso	3	49	90	15	2

Table I continued

Name of Station	T_{11}	T_{12}	T_{13}	T_{14}	T_{15}
Phoenix	5	51	81	21	1
Mondena	12	59	62	20	6
Reno	12	60	62	20	5
Boise	14	53	57	24	11
Spokane	15	48	61	19	16

T_{11} - Well above normal

T_{12} - Above normal

T_{13} - Near normal

T_{14} - Below normal

T_{15} - Far below normal

The frequency of temperature anomalies shown in the above table can be used as a reference in forecast. For instance, in Phoenix the far below normal temperature occurred only once in 159 cases, so if in a condition the temperature anomaly cannot be determined, whether it is below normal or far below normal it would be better to put it as below normal.

BASIC FORMULAE AND CALCULATIONS

Problems in matching as applied to statistical research are of fairly recent origin. The meteorological use of matching technique was first applied by Professor Epstein (3) of CIT to some WIB forecasts in problems of forecast verification. During the war Dr. D. A. Darling made a study of connection between the analogue method of forecasting and the matching problem. The advantage of this technique lies in its ability to handle qualitative data which seems to be a more fruitful analysis than that of more localized continuous phenomena which of necessity may not include large scale concepts. The general formula for all the moments in any number of variables for any combination of matches was solved by Darling (4).

The number of variables to be analyzed in the present problem are two. Let T_{1i}, which represents the categories of the temperature anormalies of the principal station, be the first variable, and T_{2j}, the categories of temperature of other stations, be the second variable. The data so classified can be tabulated as in Fig. 2 where N is the number of weeks for which the analysis is desired.

1	2	3	4	---	---	---	---	N-1	N
T_{13}	T_{12}	T_{15}	T_{14}	---	---	---	---	T_{11}	T_{14}
T_{24}	T_{22}	T_{25}	T_{25}	---	---	---	---	T_{23}	T_{22}

Fig. 2

Any one particular arrangement in Fig. 2 can be summarized into a two dimensional contingency table as in Fig. 3.

N_{11}	N_{12}	N_{13}	N_{14}	N_{15}	a_1
N_{21}	N_{22}	N_{23}	N_{24}	N_{25}	a_2
N_{31}	N_{32}	N_{33}	N_{34}	N_{35}	a_3
N_{41}	N_{42}	N_{43}	N_{44}	N_{45}	a_4
N_{51}	N_{52}	N_{53}	N_{54}	N_{55}	a_5
b_1	b_2	b_3	b_4	b_5	N

Fig. 3

The number N_{ij} signifies the number of times in Fig. 2 that the T_{1i} appears in conjugation with T . That is how many times the ith values of the first variable occurs with the jth value of the second variable. From the contingency table we can calculate the following:

Mean matches $$M_{ij} = \frac{a_i b_j}{N} \quad \text{----} \quad (1)$$

Standard deviation of matches

$$\sigma_{ij} = \frac{1}{N}\left(\frac{a_i(N-a_i)\ b_j\ (N-b_j)}{N-1}\right)^{\frac{1}{2}} \quad \text{----} \quad (3)$$

Normal deviate $$\alpha_{ij} = \frac{N_{ij} - M_{ij}}{ij} \quad \text{----} \quad (3)$$

The detail proof of the above formula is shown in the appendix.

Set up the contingency tables of temperature anormalies of the preceding week for each selected station with respect to the principal station. Calculate the normal deviate by the method shown in the last paragraph. One example of the calculation is shown in the appendix. Plot the corresponding calculated values for all the stations on a map and trace the contour lines. These contour maps show the relation between the temperature anomaly of the principal station with that of other stations of the preceding week.

In this study Nashville was used as the principal station. The temperature anomaly data used for the calculations were taken from the Weekly Weather and Crop Bulletin (6) from 1935 to 1946. The season chosen was winter. The example of the calculation is shown in the appendix.

INTERPRETATION OF CONTOUR CHARTS

The charts shown in the following pages are for the relation between the temperature anomalies at Nashville and temperature anomalies of preceding week at all other stations. The positive area of the contour charts means they are positively correlated and vice versa. To make a forecast both the positive and negative relations can be used. The method of using these charts will be discussed later.

a. Nashville - Well above normal during current week.

Other stations - Well above normal during preceding week.

The relationship is shown in Fig. 4. The well above normal temperature in the Basin area is due to continuous invasion of warm Pp air mass into that area. The fronts or troughs associated with the Pp air as in the E type (5) weather will be intensified after moving east of the Rockies, so more Tg air will be drawn inland and thus raise the temperature at Nashville in the next week. This is the reason that the well above temperature anomaly at Nashville is closely related to the well above temperature during the preceding week in the basin area.

In the eastern part of the United States from the Mississippi Valley to the Great Lakes, the well above normal temperature is due to returning Pc and Tg air. In such a condition there are two possibilities which could happen. (1) If the upper air shows a strong zonal flow there will be little chance of a Pc outbreak, so the temperature at Nashville will continue to be well above normal. (2) If it is meridional flow then a Pc outbreak can occur only over western United States with this normal deviate and it will be warm over Nashville the next week as indicated in A type (5) weather.

b. Nashville - well above normal during current week.

Other stations - above normal during preceding week.

The relation between these two temperature anomalies is shown in Fig. 5. They are not strongly correlated and only a part of the Basin area and central United States are positively correlated. A weak flow of Pp air into the Basin area with cloud cover will make the temperature above normal. Troughs associated with Pp air, as in E type (5) weather, may be intensified or redeveloped in the central United States east of the Rockies. Such a condition often continues for several days, and so may raise the temperature at Nashville by drawing in Tg air inland.

The negative normal deviate on the east coast indicates a lack of above normal temperatures in the preceding week. Had above normal temperatures occurred, it would mean that the high temperature produced by RPc had been partly compensated by some Pc air. In the winter season the continuation of the Pc outbreaks is more probable, so the chance for well above normal temperature is small.

c. Nashville - well above normal during current week.

Other stations - near normal during preceding week.

Fig. 6 shows the relation between the above two temperature anomalies. In the Basin area the near normal temperature can be caused by several conditions. If the heat of a warm Pp is compensated by night cooling, then the isobaric pattern in the Basin should be a stagnating high, and there will be a ridge over the Basin at upper levels. In such a case the chance of Pc outbreak is favorable, so there is little chance for high temperature at Nashville in the next week.

Sometimes the near normal temperature in the Basin is due to the combination of cold and warm air masses. In such a case the cold air drawn into the Basin area is only a part of the main Pc outbreak over the great plain. As there was a strong Pc outbreak in the last week and the ground is very cold, the temperature at Nashville could not be high during this week.

The combination of warmed Pp air and Pc over Nebraska gives near normal temperature over that area. But the trough developed or intensified by the foehn action can hardly produce high temperature in Nashville, because it is too far north to draw Tg air north to Nashville.

The positive normal deviates in zone VI are not the sole requirement; that is, a near normal temperature anomaly in zone VI is not always followed by a well above normal over Nashville next week. But if the near normal temperature over zone VI is accompanied by well above normal temperature over the rest of the United States area, as indicated as a requirement by Charts 4 and 5, the temperature over Nashville will most probably be well above normal next week.

d. Nashville - well above normal during current week.

Other stations - below normal during preceding week.

The relation between the above two temperature anomalies is shown in Fig. 7. When cold air comes down into the west coast, the contingent part of Basin area troughs will be developed along the coast and these troughs will be intensified when they reach zone IV, as illustrated in type A weather. Tg air will be drawn inland by this system, thus high temperature will be caused at Nashville.

Below normal temperature in Texas is often due to a trapped Pc high cell over that area. The dissipation or movement of a trapped high cell is slow. In such a case the warm air can hardly get into the land owing to the blockade by that high cell, so there is no chance for high temperature over Nashville.

The below normal temperature over the eastern part of the United States means Pc air has been prevailing during that period. Under such conditions, unless there is some evidence that some active troughs are coming into the southern part of the Basin and eventually being intensified over the eastern side of the Rockies, the temperature will not be well above normal over Nashville. Besides the three above-mentioned areas, the below normal temperature over the rest of the United States is not significant.

e. Nashville - well above normal during current week.

Other stations - far below normal during preceding week.

The relation between the above two temperature anomalies is shown in Fig. 8. The normal deviate is positive over the Basin area, which means that the far below normal temperature in that area will be followed by a high temperature at Nashville during next week. Far below normal temperature is due to the presence of a Pc air mass. This is a typical A type weather pattern with Pc air invading western United

States. A strong surge of Tg air into Mississippi will follow and raise the temperature at Nashville.

The normal deviate over zone VI is negative because, if the anomalies were normal, the ground would be too cold to be warmed up in a week, so there would be little chance to produce well above normal temperature at Nashville.

f. Nashville - above normal during current week.

Other stations - well above normal during preceding week.

The relation between the above two temperature anomalies is shown in Fig. 9. Nearly the whole map shows positive correlation. The trough in the northern part of the Basin area shown in the contour chart means that the Pp air associated with frontal activity over that part is too far north to produce any effect which can get the warm air into the area around Nashville; on the other hand cold air outbreaks are unlikely. This is the condition indicated by B type weather.

The normal deviate over the southern part of the Basin area is positive because the well above normal temperature over that area is due to the frontal activity associated with the warm Pp or Tp passing that area and the fronts will be intensified in the east side of the Rockies and will draw more warm Tg air into the area around Nashville.

When the temperature over zone III is high, it means that the Pp air current coming down from the Rockies is strong, or in other words, the zonal flow is strong so the trend for Pc outbreak is small. Moreover, if the temperature over eastern United States is well above normal, then the ground is warm so the chance for above normal temperature in the next week is more favorable than for lower temperature.

g. Nashville - above normal during current week.

Other stations - above normal during preceding week.

The relation between the above two anomalies is shown in Fig. 10. When the temperature anomaly over the great Basin and zone III is above normal, it means the Pp air flowing into those areas is not so strong as in the case of well above normal, or in other words, it is not a strong zonal flow. It is quite possible, with weak zonal flow, that some troughs, intensified over the great plains will induce a Pc outbreak. In such a condition the temperature over Nashville will not be above normal. That is why the normal deviate is negative.

In zone VI and a part of zone V the above normal temperature is due to the Tg and RPc air masses combined with a small amount of Pc. If the flow is meridional during the preceding week, there must have been a Pc outbreak, which takes the route over the western part of the United States, otherwise there would not be above normal temperatures over zone VI. This is the case of type A weather, so there will be an above normal temperature over Nashville during the next week. If the flow is zonal, then there will be no trend for Pc outbreak and the temperature will remain the same as that in the last week.

h. Nashville - above normal during current week.

Other stations - near normal during preceding week.

The relation between the above two temperature anomalies in shown in Fig. 11. In the Basin area the near normal temperature is often due to the stagnating Basin high. In such a condition there should be a ridge in the upper chart over that area, as indicated in

Bn type weather, and a persistance of such upper pattern is most likely. The chance for Pc outbreak is favorable, so the temperature at Nashville will not be above normal. If the near normal temperature is due to the combination of cold and warm air masses, then, as stated on page 13, there should be a strong Pc outbreak over the great plain. As there was a strong Pc outbreak during the last week and the cold ground could not be warmed up in a short period, the temperature at Nashville will not be high.

i. Nashville - above normal during current week.

Other stations - below normal during preceding week.

The relation between the above two anomalies is shown in Fig. 12. The maximum normal deviate is over Nevada. Cold air coming down into the Basin area and west coast is the typical characteristic of type A. Type A weather will give above, or well above normal temperature over Mississippi Valley during the following week.

A below normal temperature in eastern United States is due to prevailing Pc air mass over that area. In such a condition the zonal index should probably be very low. The chance for a sudden increase of zonal index from low to high is not likely, so the temperature over Nashville will hardly be above normal and the normal deviate must therefore be negative.

j. Nashville - above normal during current week.

Other stations - far below normal during preceding week.

The relation between the above two anomalies is shown in

Fig. 13. The condition is nearly the same as in the case shown in Fig. 12, which indicates the relation of Nashville above normal with respect to other stations below normal.

In the eastern part of the United States the chance for above normal temperature after a period of very low temperature is small because the ground covered with snow is very cold and it takes several days to warm up, so the normal deviate is negative.

The contour chart in Fig. 13 gives a more distinct relation than that illustrated in Fig. 12 because the circulation in the case of far below normal is more intense than that of below normal, and the influence on the weather of next week will be more pronounced.

k. Nashville - near normal during current week.

Other stations - well above normal during preceding week.

The relation between the above two anomalies is shown in Fig. 14. Well above normal temperature over zone I and zone II means the Pp air current flowing into that area is very strong, or in other words, it is a strong zonal flow so the chance for Pc outbreak is small, as indicated in B type weather. At the same time the chance for Tg air flow inland is also small, because the trough produced by foehn effect over zone III is too far north to have any effect to pull the Tg air inland. With no warm air and no cold air coming into the eastern United States, the temperature will be near normal.

In the area of zone VI a well above normal temperature means more Tg air flow inland, or, in other words, the zonal index of subtropical easterlies is probably low. Chance for continuous flow of Tg is favorable. So the temperature at Nashville could hardly be near normal.

l. Nashville - near normal during current week.

Other stations - above normal during preceding week.

The relation of the above two anomalies is shown in Fig. 15. The general features are similar to Fig. 14, but with the area of high normal deviate shifted to the southern part of the basin and the area of low normal deviate shifting north toward the Great Lakes. Whether the temperature over Basin area is above normal or well above normal depends upon the intensity of flow of Pp air into that area. With the assumption that the flow pattern for the two cases is the same, we can use the same argument as in Fig. 14 for the positive normal deviate over Basin area. That is, the troughs associated with Pp air mass, after being intensified over the east side of the Rockies, will suck warm air up into Nashville.

In the eastern part of the United States, above normal temperature is due to either Tg or return Pc. In either case the flow pattern is most probably meridional. That is, either a Pc outbreak or a Tg surge will follow, so the temperature at Nashville would not be near normal.

m. Nashville - near normal during current week.

Other stations - near normal during preceding week.

The relation of the above two temperature anomalies is shown in Fig. 16. Ordinarily the near normal temperature anomaly is the transient zone between above normal and below normal, so it is hard to find any significant trend for what will occur in the next week.

In the central part of the United States the temperature will be near normal if there is neither strong Pc outbreak nor strong Tg flow.

In such a condition the flow is zonal and the chance for zonal flow in the next week is favorable, so the temperature at Nashville will not change too much from normal.

The remaining part of the contour chart gives no significant relation.

n. Nashville - near normal during current week.

Other stations - near normal during preceding week.

The relation between the above two anomalies is shown in Fig. 17. The normal deviate over western United States is negative. A below normal temperature in the southern part of Basin area may be due either to the strong night radiational cooling or to the invasion of cold Pc. In the latter case it is like A type weather, and there would be higher temperature at Nashville the next week. In the former case a stagnating high is often associated with a ridge in the upper chart, so it is quite possible that a Pc outbreak may follow in the next week. In both cases there will not be a near normal temperature.

In the eastern part of zone VI the below normal temperature may be due to isolated Pc high cell located over zone VI. As soon as this Pc high cell moves slowly into the ocean, the return flow will gradually make the temperature up to near normal, so the normal deviate over this part is positive.

In zone V the below normal temperature may be due to Pc outbreak with high cell centered over eastern Canada. In such a condition the high cell is often elongated in an east-west direction rather than north-south, and stagnates for some period. Rarely will the cold air influence the temperature at Nashville. In case no other important factor occurs, the temperature at Nashville will be near normal.

o. Nashville - near normal during current week.

Other stations - far below normal during preceding week.

The relation between the above two anomalies is shown in Fig. 18. Nearly the entire chart gives negative normal deviate. A far below normal over great Basin is due to Pc invasion over that area. As shown in the characteristics of A type weather, it will be warm at Nashville in the next week, so the temperature anomaly will not be near normal. The negative normal deviate over the eastern United States is not as low as in the western part of the United States. This is because the return flow of Pc air may warm up the cold ground and raise the temperature to near normal, which would make the correlation less negative.

p. Nashville - below normal during current week.

Other stations - well above normal during preceding week.

The relation between the above two anomalies is shown in Fig. 19. When the temperature over Basin area is well above normal, the zonal flor of Pp air is strong, so there is little chance for Pc outbreak. As shown by the negative normal deviate, the temperature will not be below normal.

In the eastern United States from Mississippi Valley to Great Lakes the well above normal temperature is due to Tg and return Pc. In case of low zonal index, there should be a Pc outbreak over Basin area, and it will be warm over Nashville in the next week as indicated by the

A type weather. In case of high zonal index, there will be no Pc outbreak at all. In both cases the temperature over Nashville will not be below normal.

The region of Texas is most often invaded by return Pc when eastern United States is dominated by Pc air. In other words, when the temperature over Texas is well above normal the chance for lower temperature is favorable, so the normal deviate is slightly positive.

q. Nashville - below normal during current week.

Other stations - above normal during preceding week.

The relation between the above two anomalies is shown in Fig. 20. The positive normal deviates are confined to the northern border states starting from Washington to Great Lakes. The above normal anomaly is due to the warm Pp air brought toward those areas by the traveling troughs. Troughs along the northern border may often induce Pc outbreak down to the United States. So the temperature may become below normal at Nashville if the temperature along the northern border of the United States was above normal in the last week.

In the southern part of Basin and Texas the normal deviate is negative because if the temperature was above normal over those areas then the troughs associated with Pp air, as indicated by E type weather, would be intensified on the east side of the Rockies and Tg air would be brought in. So the temperature at Nashville will not be below normal.

r. Nashville - below normal during current week.

Other stations - near normal during preceding week.

The relation between the above two anomalies is shown in Fig. 21. The normal deviate over great Basin is positive because, as interpreted in the preceding sections, the near normal temperature over great Basin will most probably be followed by a Pc outbreak into the great plain. As shown by the normal deviate, the temperature at Nashville will be below normal.

The rest of the areas of the contour curves give no significant characteristics.

s. Nashville - below normal during current week.

Other stations - below normal during preceding week.

The relation between the above two anomalies is shown in Fig. 22. The diagonal line drawn from Florida to Montana divides the whole picture into two zones, one with positive normal deviate and the other with negative normal deviate.

The positive normal deviate is over Utah, Colorado and New Mexico. As shown in AB type weather, a strong Pc outbreak brought into western United States following the first major trough makes the entire continent temperature below normal. A part of the Pc air sweeps into the eastern United States and a part of the Pc stagnate over the Basin area. The stagnating high tends to blockade the troughs traveling into Mississippi Valley, so there is no chance to warm up that area.

A low negative normal deviate is over the area around Great Lakes. If this had been a positive normal deviate, then below normal temperature over that area would be due to a weak Pc outbreak. The returning Pc would eventually heat up the area at Nashville, therefore the temperature would not be below normal during the next week, so the normal deviate cannot be positive.

t. Nashville - below normal during current week.

Other stations - far below normal during preceding week.

The relation between the above two temperature anomalies is shown in Fig. 23. A far below normal temperature over the Basin area is due to a Pc outbreak over that area. As indicated by A type weather, the temperature over Nashville would be above normal during the next week, so the normal deviate is negative.

In the eastern half of the United States the far below normal temperature is due to a strong Pc outbreak. The cold ground covered with snow cannot be heated up within a short time, so the chance for below normal temperature is favorable.

u. Nashville - far below normal during current week.

Other stations - well above normal during preceding week.

The relation between the above two anomalies is shown in Fig. 24. Nearly the whole picture shows negative normal deviate. The well above normal temperature over the zone of prevailing westerlies is due solely to strong zonal flow. The chance for abrupt change from zonal flow to meridional flow is very small, so there will be no low temperature over Nashville during the next week. This is why the normal deviate over the whole continent is negative.

v. Nashville - far below normal during current week.

Other stations - above normal during the preceding week.

The relation between the above two anomalies is shown in Fig. 25. The whole picture shows the same feature as Fig. 24. The only difference is that the two centers of the contour lines in the two figures are opposite in sign. One is a center of decreasing negative values while the other is a center of increasing negative value. The warm Pp air associated with some troughs over the great plain may sometimes induce a Pc outbreak, which is why the center of normal deviate located on the west of the Great Lakes is less negative.

w. Nashville - far below normal during the current week.

Other stations - near normal during the preceding week.

The relation between the above two anomalies is shown in Fig. 26. The normal deviate over the great Basin is positive because, as interpreted in the preceding sections, the near normal temperature over great Basin will possibly be followed by a Pc outbreak into the great plain.

Along the eastern United States the near normal temperature may either be due to combination of Pc and RPc or due to Pp air mass as in B type weather. In both cases there would be no trend for strong Pc outbreak such that the temperature over Nashville will be far below normal in the next week, so the normal deviate over eastern United States is negative.

x. Nashville - far below normal during the current week.

Other stations - below normal during the preceding week.

The relation between the above two anomalies is shown in Fig. 27. A below normal temperature over the great Basin would often be followed by warm temperature over the Mississippi Valley, as shown in the A type weather. So the temperature over Nashville will not be far below normal.

Below normal temperature over eastern United States means that a Pc high will predominate over that area. As it is a cold high, in the upper level there should be a trough, and at the same time there should be a ridge over the great Basin. In such a flow pattern the chance for continuation of Pc outbreak is favorable, so the normal deviation is positive over eastern United States.

y. Nashville - far below normal during the current week.

Other stations - far below normal during the preceding week.

The relation between the above two anomalies is shown in Fig. 28. Nearly the whole picture shows positive normal deviate. A strong Pc outbreak stretched from north to south over the great part of the United States means the zonal index is very low, so a continuous Pc outbreak is more favorable. Therefore, the normal deviate is positive. The trough of the contour lines stretched from Mississippi Valley to the Great Lakes is very interesting, because it is the path of RPc which tends to raise the temperature.

The far below normal temperature over the east of the Appalachians is undoubtedly due to predominance of Pc air. As interpreted in the last section, a trough should be in the upper level over that area and a continuous flow of Pc outbreak is favorable.

TECHNIQUE OF FORECASTING

The weekly temperature change of a certain locality is treated as the combined effect of the weather over different areas during the preceding week. An ideal correlation of temperature cannot be obtained simply by two dimensional contingency tables. The number of possible combinations of temperature anomalies over different areas is immense; it is impracticable to get the multiple effect of them. Owing to the inadequacy of the two dimensional contingency table method, it is necessary to make some adjustment in using the contour curves to make a forecast. The following procedure has been used:

(a) Draw the temperature anomaly chart of the preceding week. Shade the different anomalies with different colors.

(b) Look at the synoptic map of the preceding week to get a clear idea of the causes of temperature anomalies at different localities, because different synoptic conditions can yield the same temperature anomaly. For instance, in the Basin area below normal temperature may be due either to strong night cooling or to invasion of Pc air.

(c) Check the current weather pattern with the ideal weather types. Two different weather types may give the same temperature change in a certain area even though the air masses in the two cases are the same. For instance, both 41a (7) and 41b weather types have a stagnating high over the Basin area and cause the temperature to go slightly above normal, but one has Foehn effect over the east side of the Rockies while the other does not.

(d) Pick up the areas of different temperature anomalies such as above normal, well above normal, etc.

(e) Combine some narrow transient zones and some small central spots to those large main areas surrounding them.

(1) $-3^{\circ}F$ combine to below normal.

(2) $+3^{\circ}F$ combine to above normal.

(3) $-9^{\circ}F$ combine to far below normal.

(4) $+9^{\circ}F$ combine to well above normal.

(5) $-10^{\circ}F$ combine to above normal

(6) $+10^{\circ}F$ combine to below normal.

(7) $+4^{\circ}F$ and $-4^{\circ}F$ combine to normal.

(f) Check the different areas of anomalies with the contour curves of normal deviate. If the area corresponds to the area of positive normal deviate, then we take the corresponding anomaly as our forecast. It is impossible to get a complete coincidence of the temperature anomaly curves and contour curves. We can only make the forecast from those partially coinciding areas. If the coinciding area is too small, we discard it.

(g) Use the negative area as a guide to exclude those temperature anomalies which are negatively correlated.

(h) Put more weight on the area of contour curves over the western part of the chart, because the change of weather in the eastern part has less influence on the weather of the following week.

(i) Put less weight on the corresponding area which is derived from the relation to near normal. Because near normal is the boundary zone between above normal and below normal, it is hard to determine the trend for what will happen in the next week.

(j) Repeat the foregoing process with different principal stations until enough points are obtained to determine the temperature anomaly of a certain area. This step is very important, because the consistency of the forecasts for several neighboring stations makes the forecast more reliable.

EXAMPLES

The following examples are made from the data from 1925 to 1935 for winter season:

(a) Figs. 29A and B show the forecast for well above normal temperature at Nashville by comparing the temperature anomaly chart with the normal deviate charts. From Fig. 8 we find a positive area of normal deviate over the west of the Rockies corresponds very well with the area of well above normal over the same area. The well above normal area over southeastern United States shown on Fig. 29A corresponds very well with the positive normal deviate over the same area shown in Fig. 4. Both cases suggest that the temperature of the following week will be "well above normal", and it is checked correctly as illustrated in Fig. 29B. In 30A the well above normal over the area west of the Rockies corresponds very well with the positive normal deviate over the same area, but the far below normal over southeastern United States corresponds with the negative normal deviate over that area. In such a condition we choose the western part as the forecasting reference. As shown in Fig. 30B it is checked correctly.

(b) In Fig. 31A the far below normal over midwest and central United States corresponds very well with the positive normal deviate over the same area shown in Fig. 28. A transient belt of below normal temperature surrounding that area can be regarded as far below normal temperature, because they are approximately due to the same air mass. The near normal temperature over the east coast of the

United States corresponds with the negative normal deviate over that area as shown in Fig. 26. In such a condition we discard the reference area of near normal temperature. From Fig. 28 we get the forecast temperature as "far below normal" and it is checked correctly as shown in Fig. 31B.

(c) In Fig. 32A the above normal over the area west of the Rockies corresponds with the positive normal deviate over the same area in Fig. 15. The below normal over eastern United States corresponds with the positive normal deviate over that area in Fig. 17. Both cases indicate that the temperature of the following week will be "near normal", and it is checked correctly as shown in Fig. 32B The far below normal over Texas, Oklahoma and lower Mississippi Valley is probably due to an isolated Pc high cell and will not give too much influence to the temperature in the following week, so we discard it.

(d) In Fig. 33A the near normal temperature over the area west of the Rockies corresponds very well with the positive normal deviate over the same area in Fig. 21. The above normal temperature over the midwest and normal part of the Great Lakes corresponds fairly well with the positive normal deviate in Fig. 20. In both cases the temperature will be "below normal" and it is checked correctly as shown in Fig. 33B. The near normal temperature over the rest of the area gives no significance.

(e) In Fig. 34A the well above normal over the Basin area and Texas corresponds very well with the positive normal deviate over the same area in Fig. 4. In the same two figures the well above normal over eastern United States corresponds very well with the positive normal deviate over that area. However, the forecasted temperature contradicts the observed value. The main reason is that the activity of troughs associated with Pp air is too far north, as indicated in precipitation chart, Fig. 34C. It not only cannot pull warm Tg air into the Mississippi Valley, but may also induce a Pc outbreak over the great plain. By no means will it produce high temperature over Nashville. From Fig. 14 it shows that high temperature over northwestern United States will be followed by near normal temperature at Nashville, and it is checked right in Fig. 34B. The well above normal temperature over eastern United States corresponds to the negative normal deviate over that area in Fig. 14. But as the weather of the eastern part has less effect on the temperature at Nashville, it is better to take the area over western United States as the forecast reference.

CONCLUSION

The results of the contour curves have been checked with the data from 1925 to 1935. As a forecasting technique it can be claimed seventy per cent reliable, checked for the right sign. As the upper charts play an important role on the weather and as in this work there is no direct consideration of the upper charts, it is obvious that sometimes this method may fail in forecast. However, it should be pointed out that one method cannot be used indiscriminately at all times; the forecast problem is really a synthesis of several tools.

The advantage of this method is that it can be used objectively without too much ambiguity. In the five-day forecast procedure of the United States Weather Bureau there is the difficulty of determination of the route of Pc outbreak, because the zonal index does not show what longitude the outbreak will take. In the weather type method there is also a difficulty in determining the following weather type during transient period.

The circulation over Canada and eastern Pacific has very important effects upon the weather over western and northern parts of the United States. It is necessary to include those areas in working this problem if the data are available.

The mean flow patterns of two consecutive weeks are undoubtedly very closely correlated. The result will be improved if the pressure anomalies are used as reference to forecast the temperature anomalies.

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APPENDIX I

Derivation of equations (1) and (2).

As it is dealing only with a single cell out of the N by K contingency table each time, so the problem is actually a 2 by 2 case.

Let T_{11} be one of the values of variable T_1

T_{12} represent the rest of the values of variable T_1

T_{21} be one of the values of variable T_2

T_{22} represent the rest of the values of variable T_2

N_{11} = number of times T_{11} and T_{21} occur together

N_{12} = number of times T_{11} and T_{22} occur together

N_{21} = number of times T_{12} and T_{21} occur together

N_{22} = number of times T_{12} and T_{22} occur together

a_1 = number of times T_{11} occurs

a_2 = number of times T_{12} occurs

b_1 = number of times T_{21} occurs

b_2 = number of times T_{22} occurs

Then a contingency table can be made from these relations.

	T_{21}	T_{22}	
T_{11}	N_{11}	N_{12}	a_1
T_{12}	N_{21}	N_{22}	a_2
	b_1	b_2	N

Fig. 36

From Fig. 2, the equally likely occurrence of T_{11}, T_{12}, T_{21} or T_{22} is $(N!)^2$, because there are N chances in each category. Out of $(N!)^2$ variants $a_1!\ a_2!\ b_1!\ b_2!$ are the same, so the probability of getting Fig. 2 is

$$(a.1) \qquad \frac{a_1!\ a_2!\ b_1!\ b_2!}{(N!)^2} = \frac{1}{\binom{N}{a_1}\binom{N}{b_1}} ,$$

where $\binom{N}{a_1} = \frac{N!}{a!(N-a_1)!} = \frac{N!}{a_1!a_2!}$; $\binom{N}{b_1} = \frac{N!}{b_1!b_2!}$.

Out of the $(N!)^2$ arrangement of Fig. 2 there are

$$(a.2) \qquad \frac{N!}{N_{11}!\ N_{12}!\ N_{21}!\ N_{22}!}$$

leading to Fig. 36. The joint probability of getting Fig. 2 and Fig. 36 is the product of (a.1) and (a.2),

$$(a.3) \qquad \frac{a_1!\ a_2!\ b_1!\ b_2!}{(N!)^2}\ \frac{N!}{N_{11}!\ N_{12}!\ N_{21}!\ N_{22}!} = \frac{1}{N!} \cdot \frac{a_1!\ a_2!\ b_1!\ b_2!}{N_{11}!\ N_{12}!\ N_{21}!\ N_{22}!}$$

Let m = number of matches in the upper left cell of Fig. 36

Then $N_{11} = m$, $N_{12} = a_1 - m$,

$N_{21} = b_1 - m$, $N_{22} = N-a_1-b_1-m$.

Probability of m matches is then

$$(a.4) \qquad p(m) = \frac{1}{N!}\ \frac{a_1!(N-a_1)!\ b_1!(N-b_1)!}{m!(a_1-m)!\ (b_1-m)!(N-a_1-b_1+m)!}$$

$$= \frac{1}{\binom{N}{a_1}} \cdot \binom{b_1}{m}\binom{N-b_1}{a_1-m}$$

The accumulating probability is

$$\text{(a.5)} \qquad P(m) = \sum_{j=m}^{b_1} p(j) = \frac{1}{\binom{N}{a_1}} \sum_{j=m}^{b_1} \binom{b_1}{j} \binom{N-b_1}{a-j} \quad \text{for } b_1 \leq a_1$$

$$= \sum_{j=m}^{a_1} p(j) = \frac{1}{\binom{N}{b_1}} \sum_{j=m}^{a_1} \binom{a_1}{j} \binom{N-a_1}{a_1-j} \quad \text{for } a_1 \leq b_1$$

The coefficient of the term $\alpha_1^{a_1} \alpha_2^{a_2} \beta_1^{b_1} \beta_2^{b_2} z^m$ in a multinomial expansion of

$$\text{(a.6)} \qquad F(\alpha, \beta, z) = \frac{a_1!\, a_2!\, b_1!\, b_2!}{(N!)^2} (\alpha_1 \beta_1 z + \alpha_2 \beta_1 + \alpha_1 \beta_2 + \alpha_2 \beta_2)^N$$

$$= \frac{a_1!\, a_2!\, b_1!\, b_2!}{(N!)^2} \sum \frac{N!}{N_{11}!\, N_{21}!\, N_{12}!\, N_{22}!}$$

$$\cdot (\alpha_1 \beta_1 z)^{N_{11}} (\alpha_2 \beta_1)^{N_{21}} (\alpha_1 \beta_2)^{N_{12}} (\alpha_2 \beta_2)^{N_{22}}$$

is equal to $P(m)$, where $N_{11} + N_{21} + N_{12} + N_{22} = N$. If we have a function

$$\text{(a.7)} \qquad \varphi(z) = \sum_{j=o}^{b_1} j\, z^{j-1}\, p(j)$$

Then the first moment $\mu_1 = \varphi'(z)\Big|_{z=1} = \sum_{j=o}^{b_1} j p(j)$

Hence the mean number of matches can be found by differenciating $F(\alpha, \beta, z)$ with respect to z

$$\text{(a.8)} \qquad \frac{\partial F}{\partial z}\Big|_{z=1} = \frac{a_1!\, a_2!\, b_1!\, b_2!}{(N!)^2} N (\alpha_1 \beta_1)(\alpha_1 + \alpha_2)^{N-1} (\beta_1 + \beta_2)^{N-1}$$

$$= \frac{a_1!\, a_2!\, b_1!\, b_2!}{(N!)^2} \cdot N \left[\sum \binom{N-1}{j} \alpha_1^{j+1} \alpha_2^{N-1-j} \right] \left[\sum \binom{N-1}{k} \beta_1^{k+1} \beta_2^{N-1-k} \right]$$

Put $\qquad j + 1 = a_1 \qquad\qquad k + 1 = b_1$

$\qquad\qquad N - j - 1 = N - a_1 \qquad N - k - 1 = N - b_1$

Then $$\mu_1 = \frac{a_1!\ a_2!\ b_1!\ b_2!}{(N!)^2} \cdot \binom{N-1}{a_1-1} \binom{N-1}{b_1-1} \cdot N$$

$$= \frac{a_1!\ a_2!\ b_1!\ b_2!}{(N!)^2} \cdot \frac{(N-1)!}{(a_1-1)!\ (N-a_1)!} \cdot \frac{(N-1)!}{(b_1-1)!\ (N-b_1)!} \cdot N$$

(a.9) $$= \frac{a_1 b_1}{N} .$$

From (a.7) we get

$$\varphi''(Z)\Big|_{Z=1} = \sum_{j=o}^{b_1} j(j-1)\ p(j)$$

(a.10) $$= \sum_{j=o}^{b_1} j^2\ p(j) - \mu_1$$

Since $$\frac{\partial^2 F}{\partial Z^2}\Big|_{Z=1} = \frac{a_1!\ a_2!\ b_1!\ b_2!}{(N!)^2}\ N\ (N-1)\ \alpha_1^2 \beta_1^2 (\alpha_1\beta_1 + \alpha_1\beta_2 + \alpha_2\beta_2 + \alpha_2\beta_1)^{N-}$$

it is easy to show as in (a.8) and (a.9) that

(a.11) $$\sum_{j=o}^{b_1} j(j-1)\ p(j) = \frac{a_1 b_1 (a_1 - 1)\ (b_1 - 1)}{N(N-1)}$$

and $$\sigma^2 = \sum (j-\mu_1)^2\ p(j)$$

$$= \sum j^2 p(j) - \mu_1^2$$

$$= \frac{a_1 b_1 (a_1-1)\ (b_1-1)}{N(N-1)} + \frac{a_1 b_1}{N} - \frac{a_1^2 b_1^2}{N^2}$$

$$= \frac{1}{N^2}\left(\frac{a_1 b_1 a_2 b_2}{N-1}\right) .$$

APPENDIX 2

An example of the calculation

T_{1i} \ T_{2j}	T_{21}	T_{22}	T_{23}	T_{24}	T_{25}	
T_{11}	4	0	4	2	2	12
T_{12}	15	2	7	7	4	35
T_{13}	25	12	10	10	6	63
T_{14}	5	12	4	3	5	29
T_{15}	1	2	4	4	9	20
	50	28	29	26	26	159

In the above contingency table T_{2j} refers to the temperature anomalies at Bismarck and T_{1i} refers to the temperature anomalies at Nashville. To get the relation between each combination of T_{1i} and T_{2j} we first set up a two by two contingency table which includes the cell to be tested, and then calculate the normal deviate.

Relation between T_{11} and T_{21}:

4		12
		147
50	109	159

$$M_{11} = \frac{50 \times 12}{159} = 3.78$$

$$\sigma_{11} = \frac{1}{159}\left(\frac{50 \times 109 \times 147 \times 12}{158}\right)^{\frac{1}{2}} = 1.55$$

$$\alpha_{11} = \frac{4 - 3.78}{1.55} = 0.14$$

All the other combinations between T_{1i} and T_{2j} can be treated in the same way.

APPENDIX 3

Skill Score

The result has been checked with 127 cases and it shows that about 84 cases are hit under the correct sign. Cases of far below normal are combined to below normal and cases of well above normal are combined to above normal. The checked result is shown in the following contingency table:

Fest \ obs	A.N.	N.N	B.N	
A.N.	27	7	3	37
N.N	5	33	13	51
B.N	7	8	24	39
	39	48	40	127

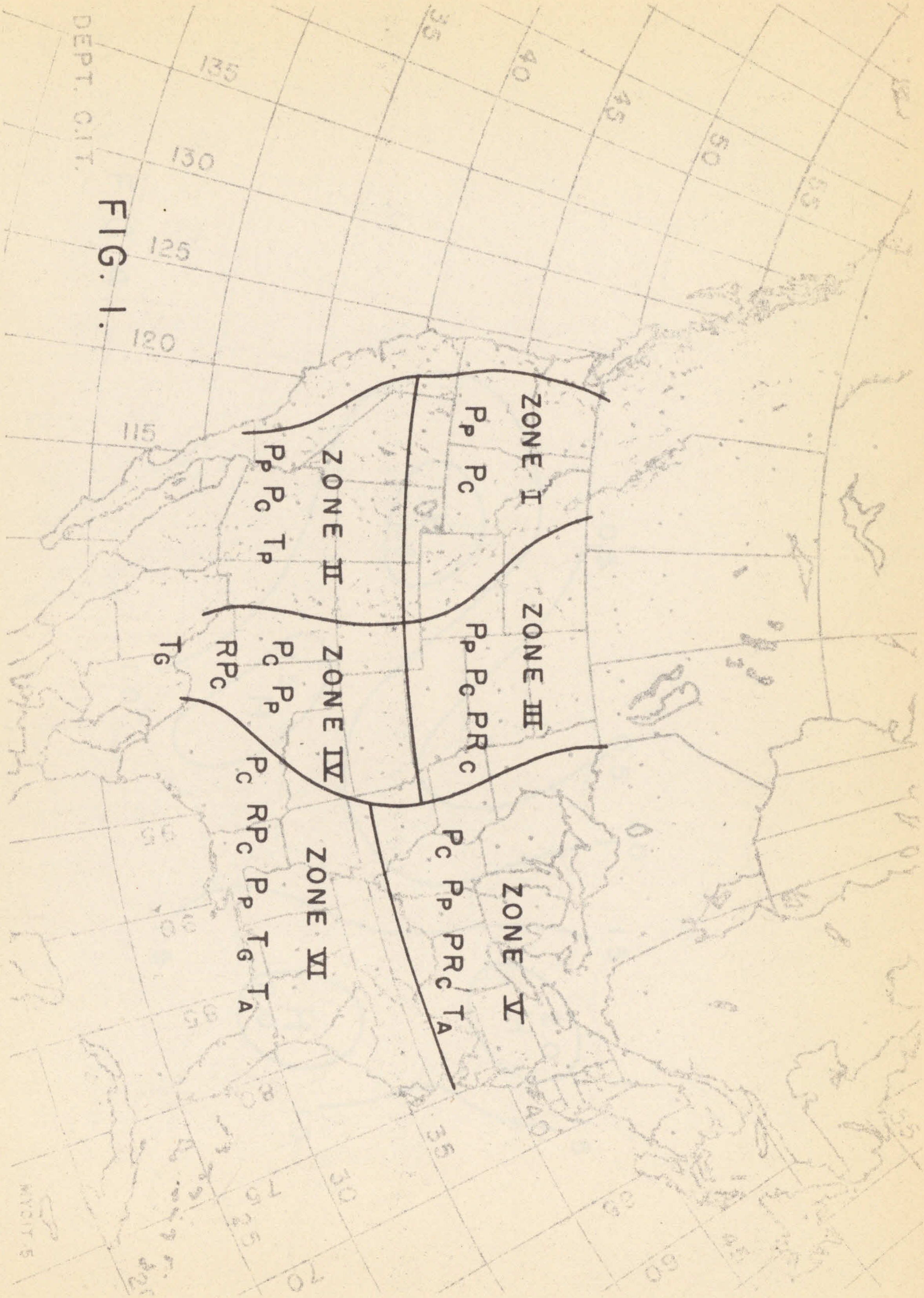
$$\text{Expected value} = \frac{37 \cdot 39 + 51 \cdot 48 + 40 \cdot 39}{127}$$

$$= 42.9$$

$$\text{Skill score} = \frac{84 - 42.9}{127 - 42.9}$$

$$= 0.48$$

The skill score is a little higher than it should be. It would be about 0.3 if the result had been checked according to correct category.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ZONE II
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ZONE III
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ZONE IV
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RP_C
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ZONE V
P_C P_P PR_C T_A
ZONE VI
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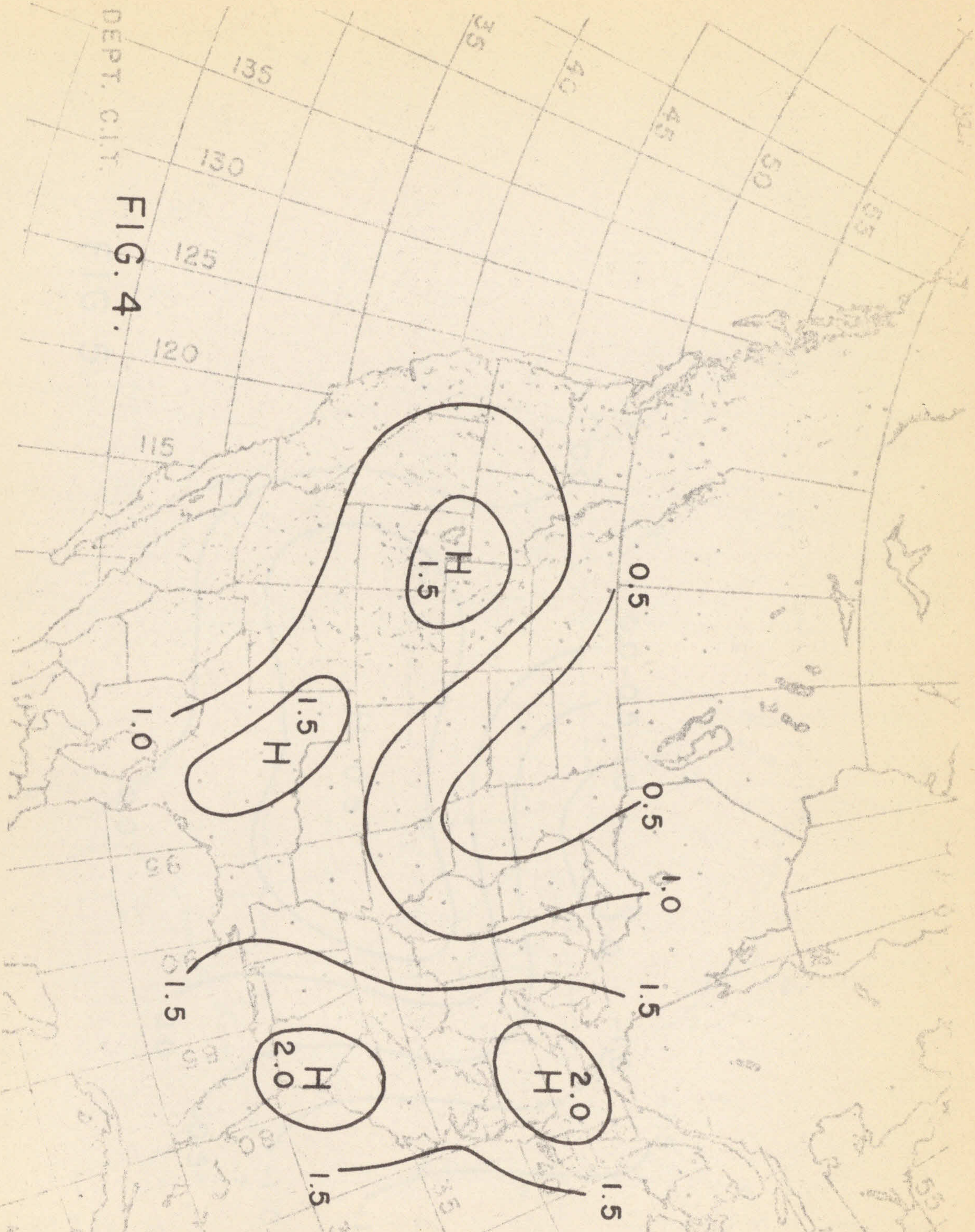
FIG. 1.

FIG. 4.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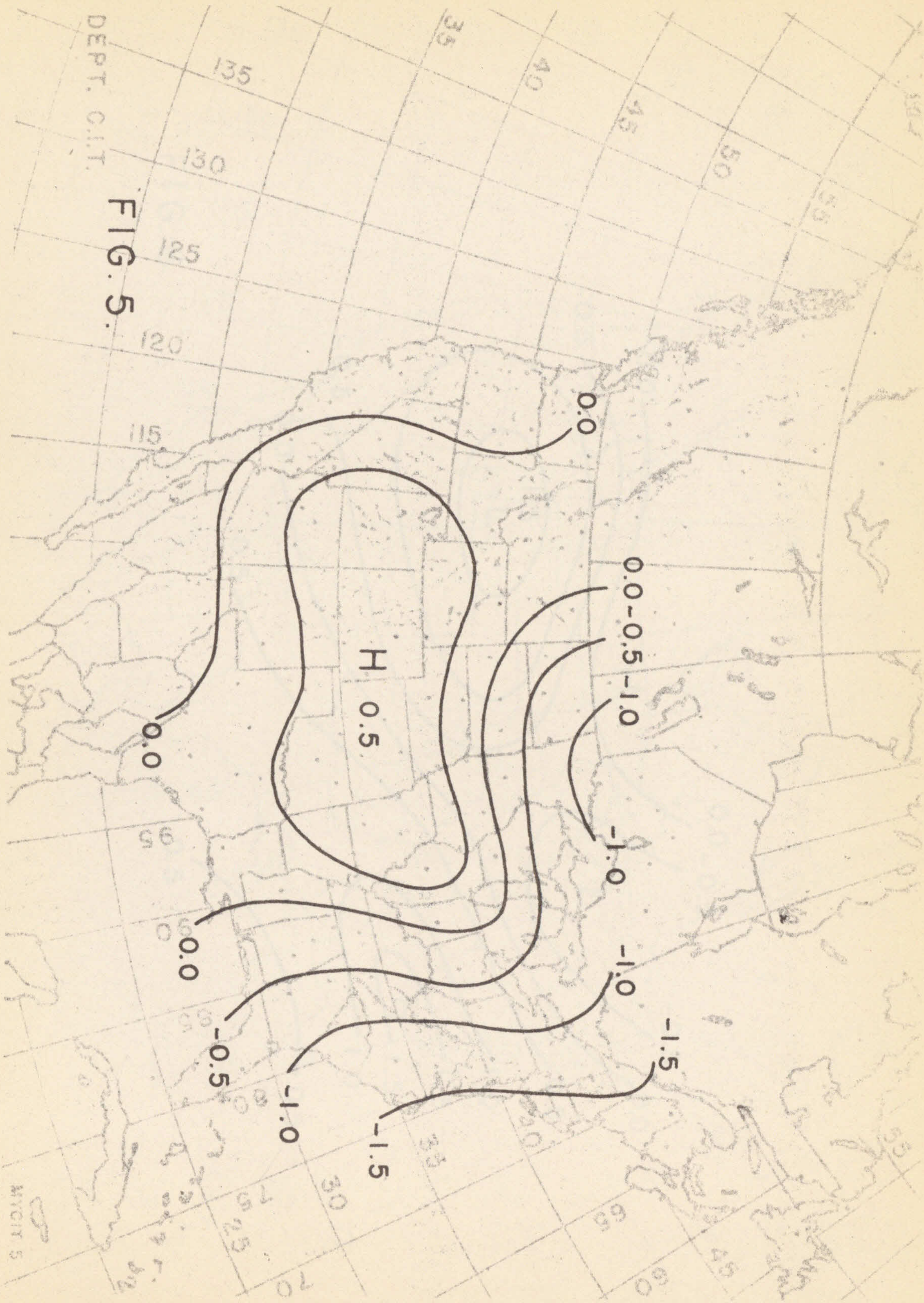

FIG. 5.

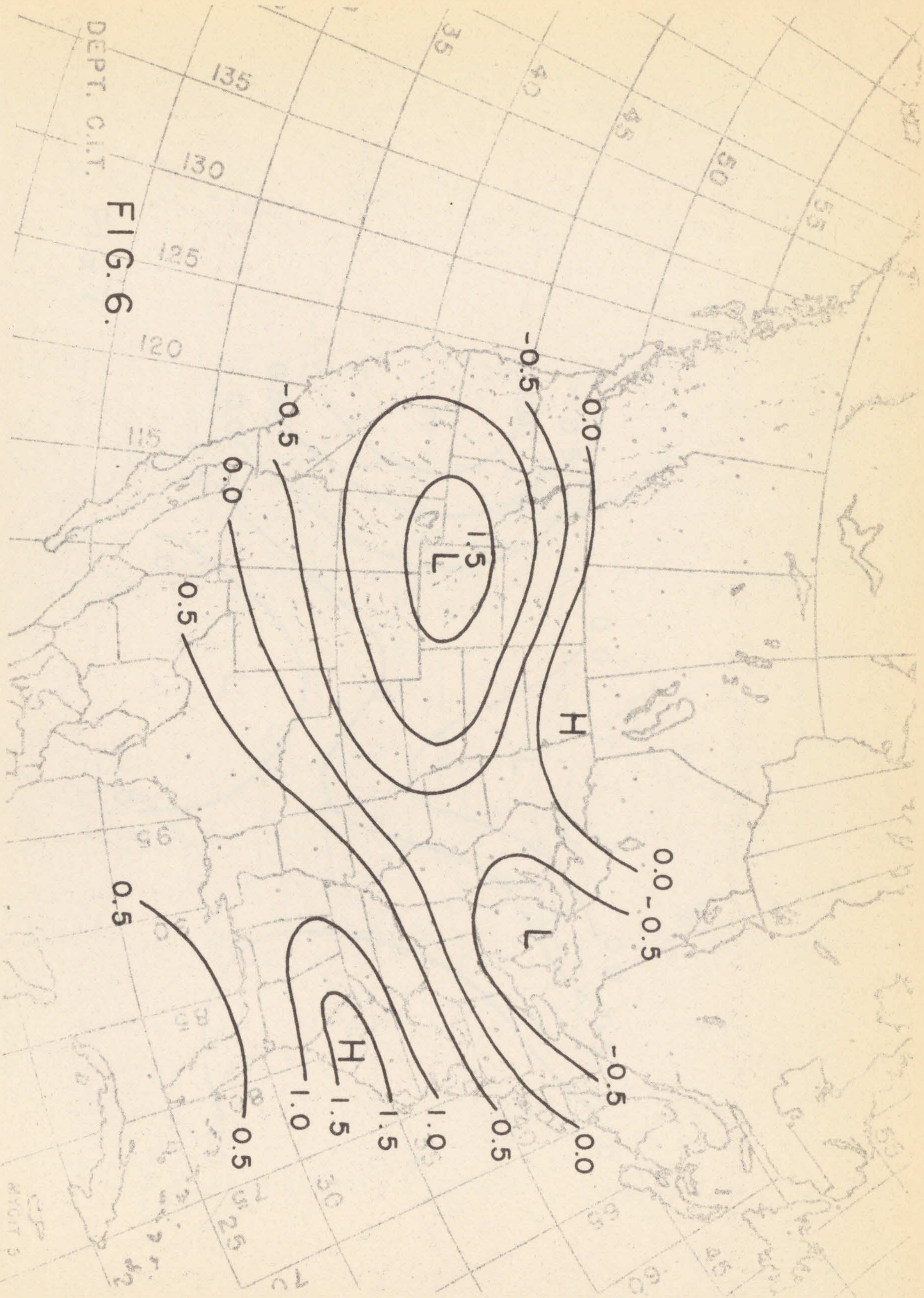

FIG. 6.

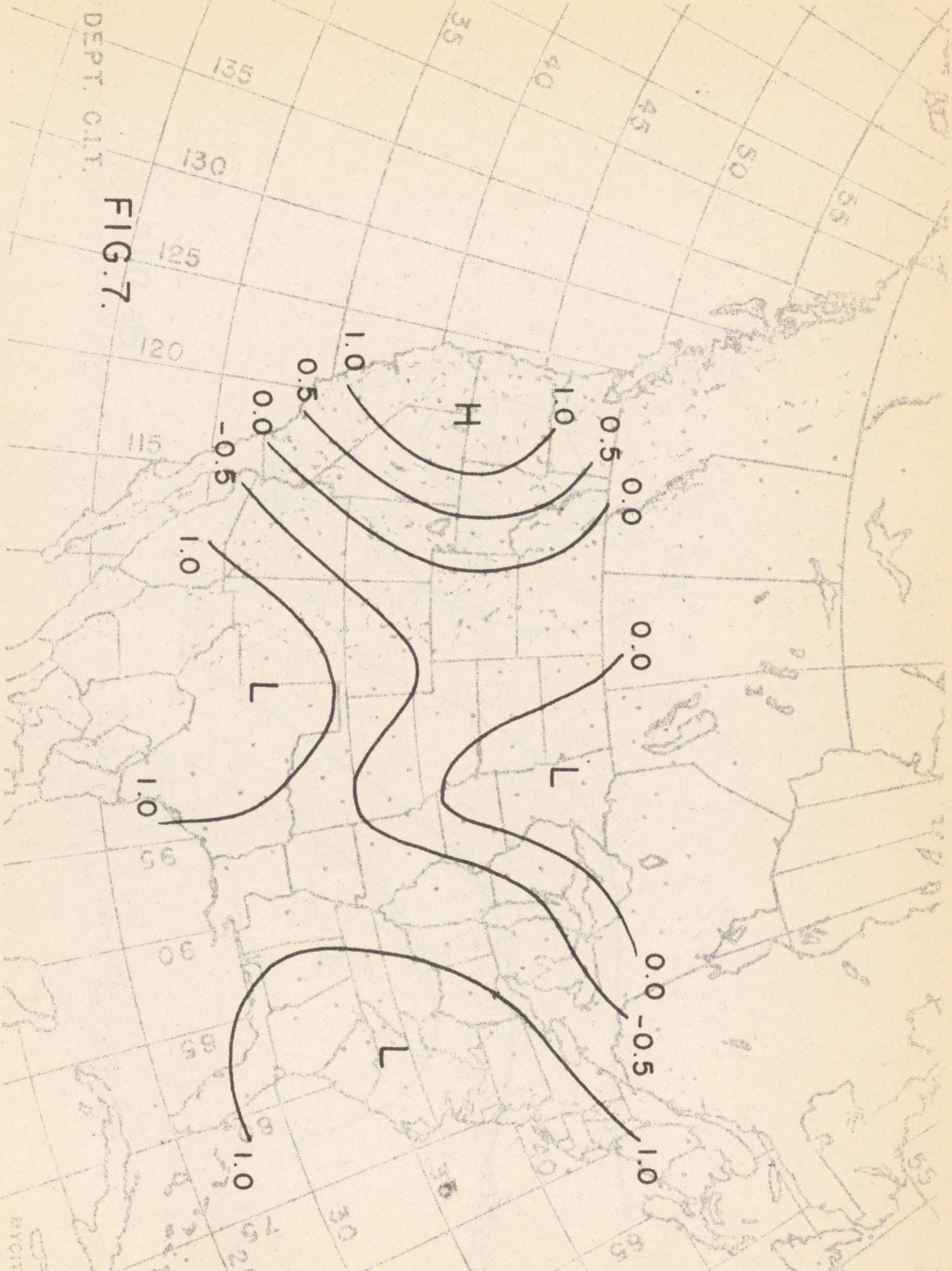

FIG.7.

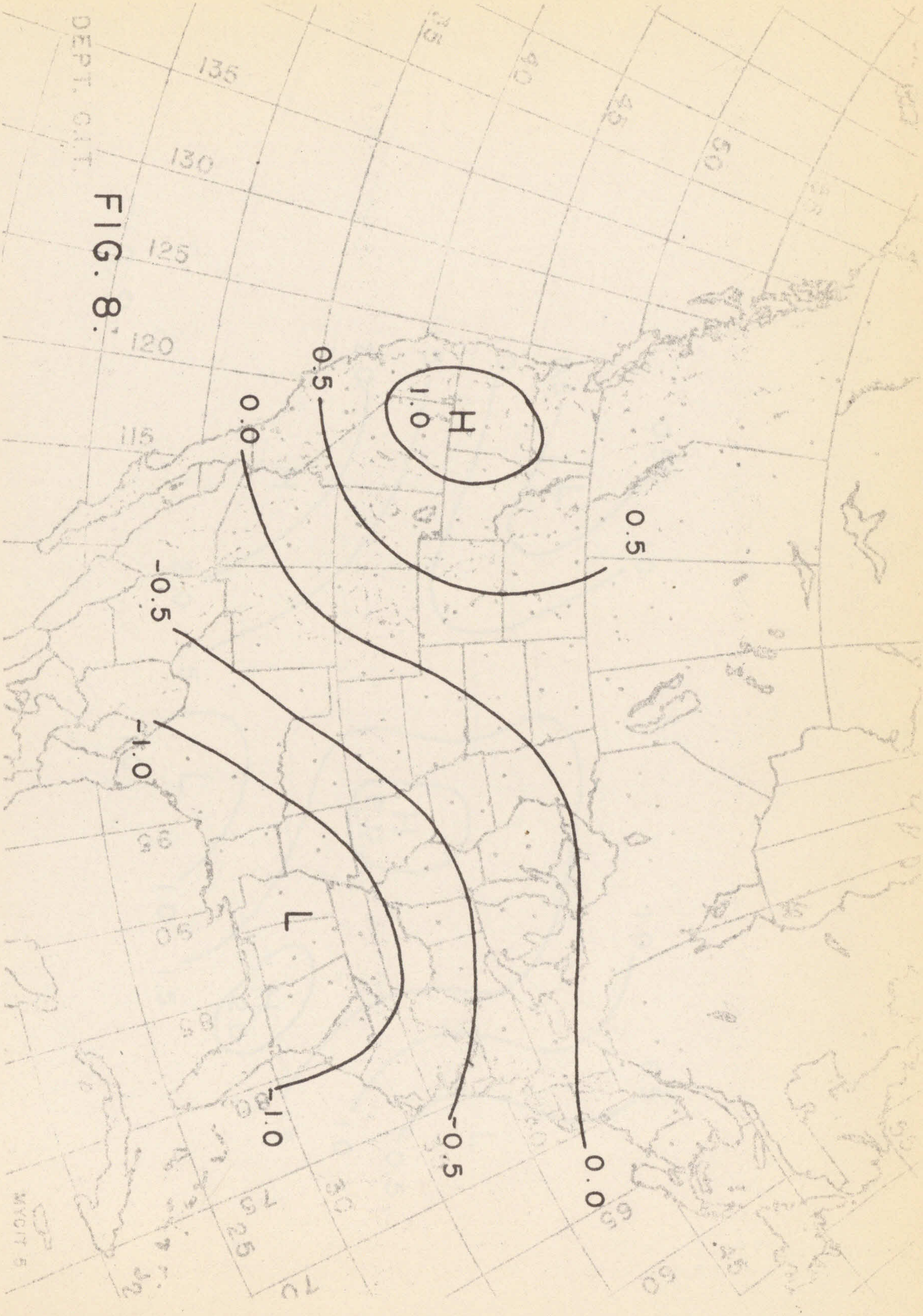

FIG. 8.

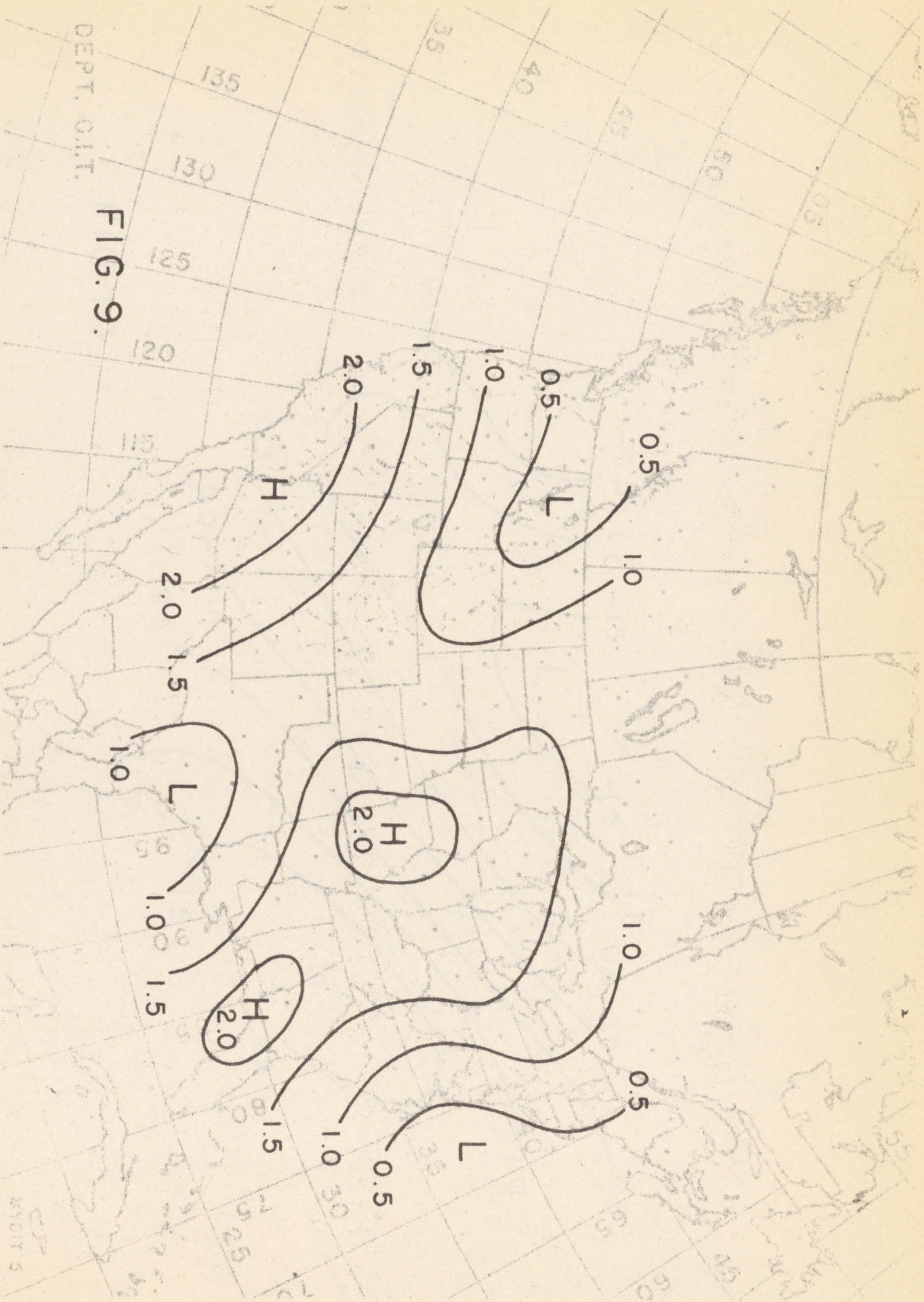
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FIG. 9.

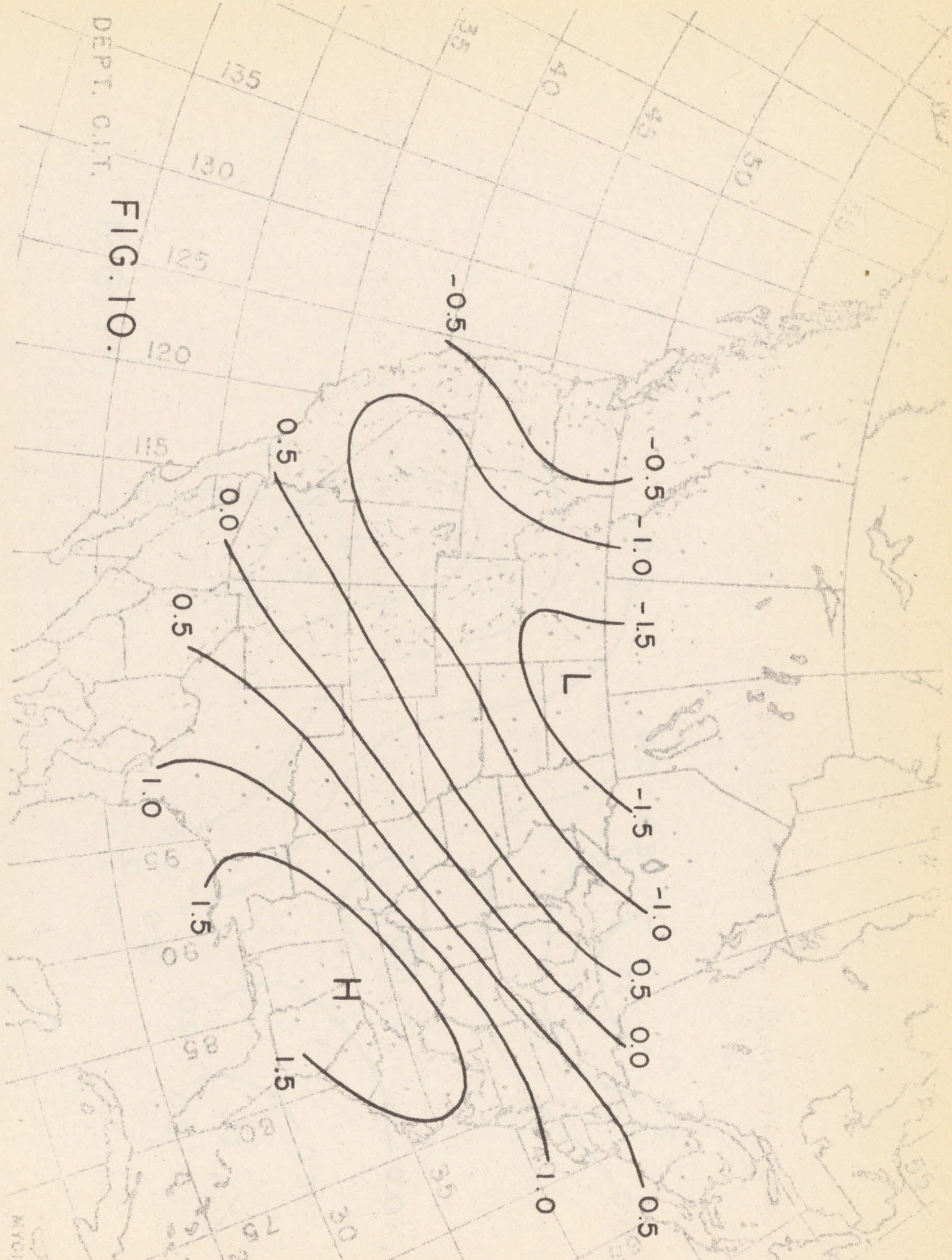

FIG. 10.

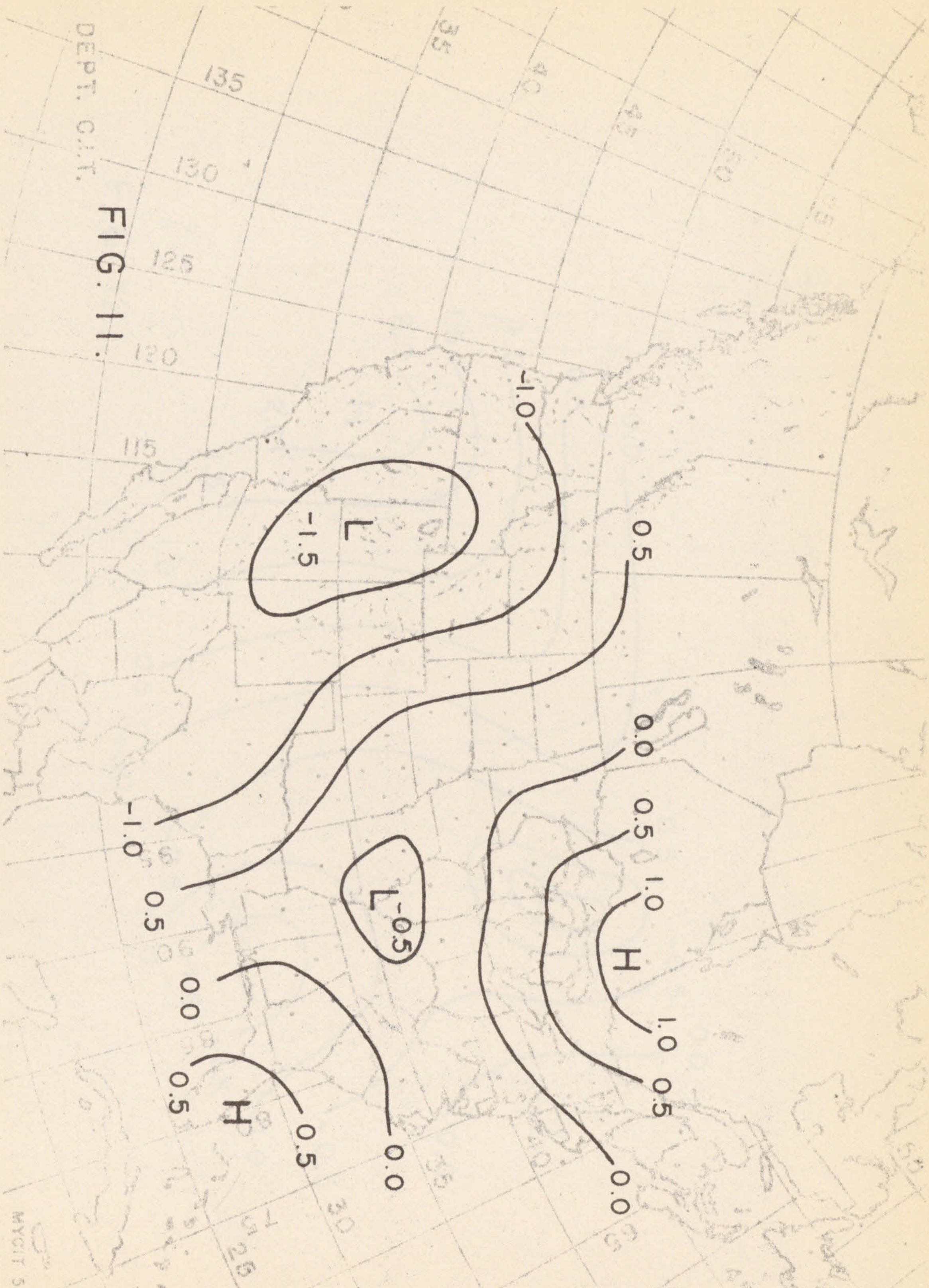

FIG. 11.

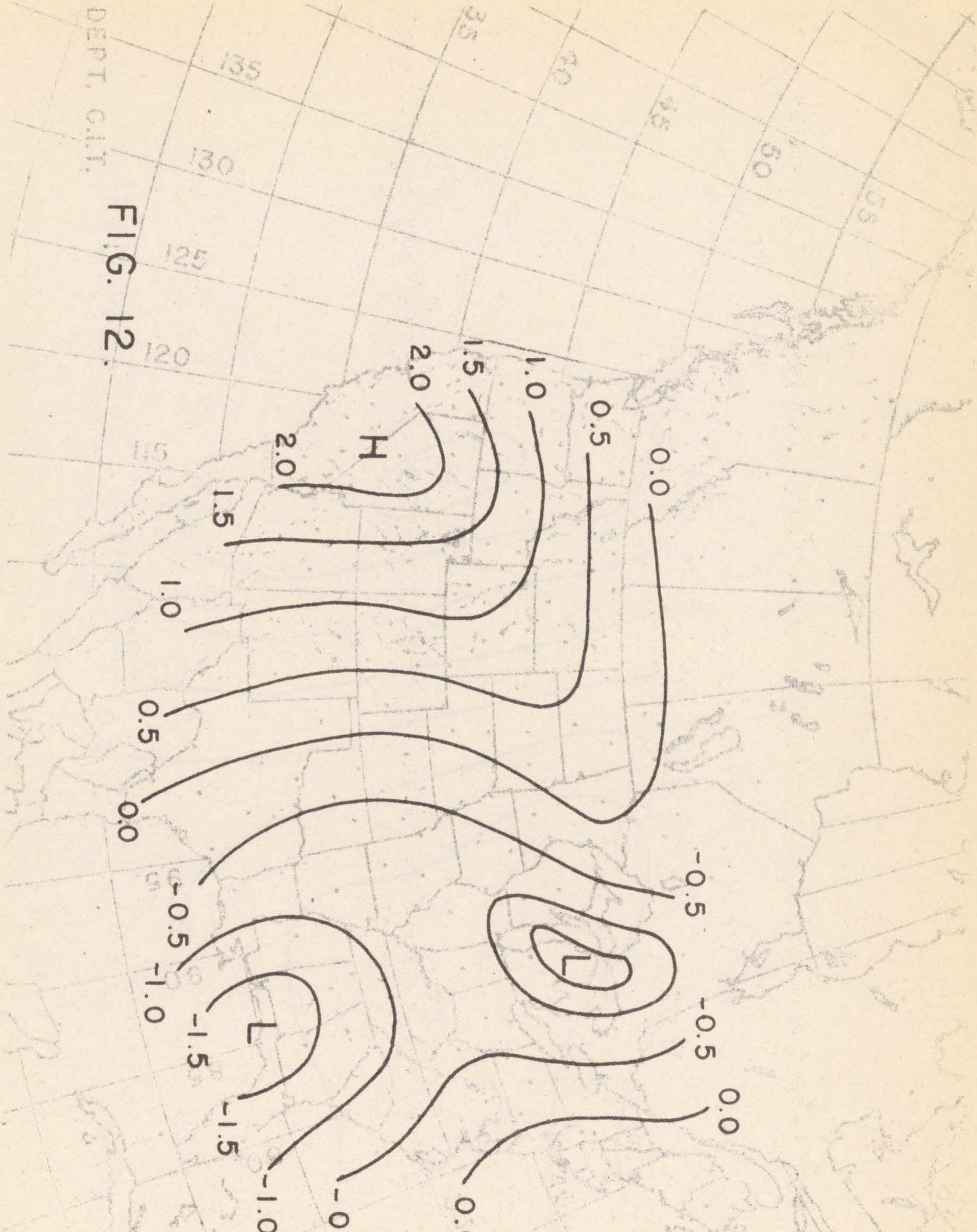
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FIG. 12.

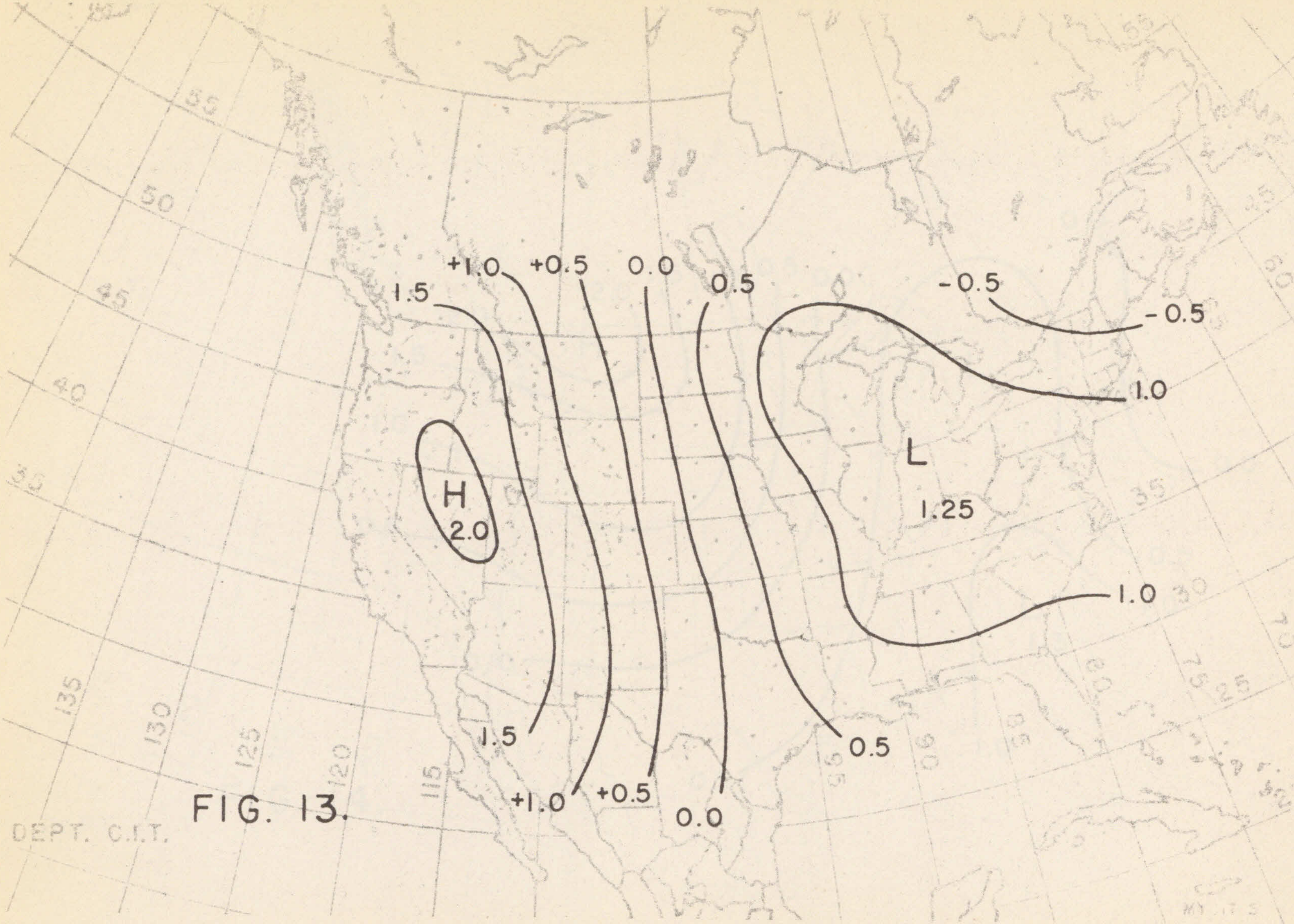

FIG. 13.

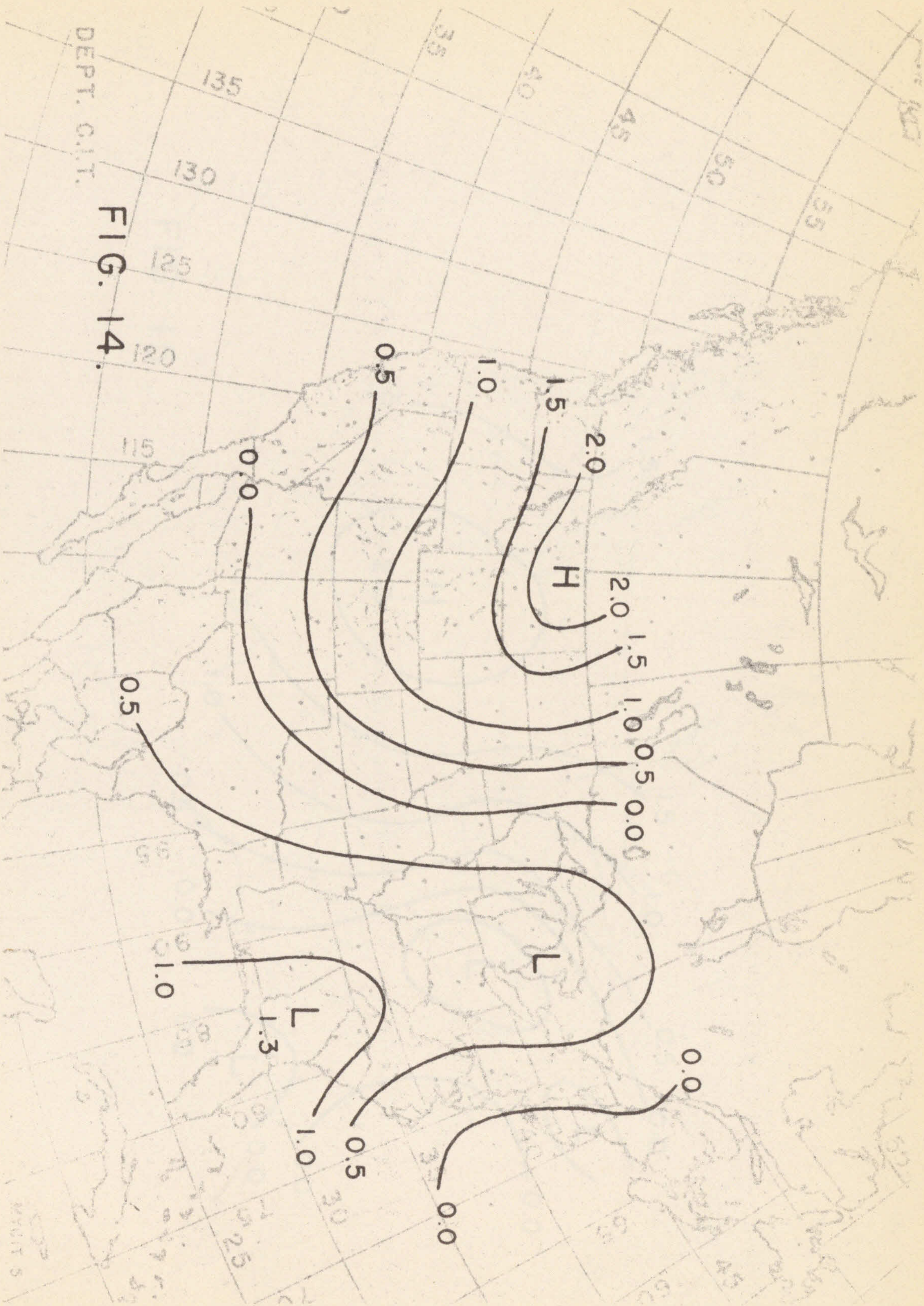

FIG. 14.

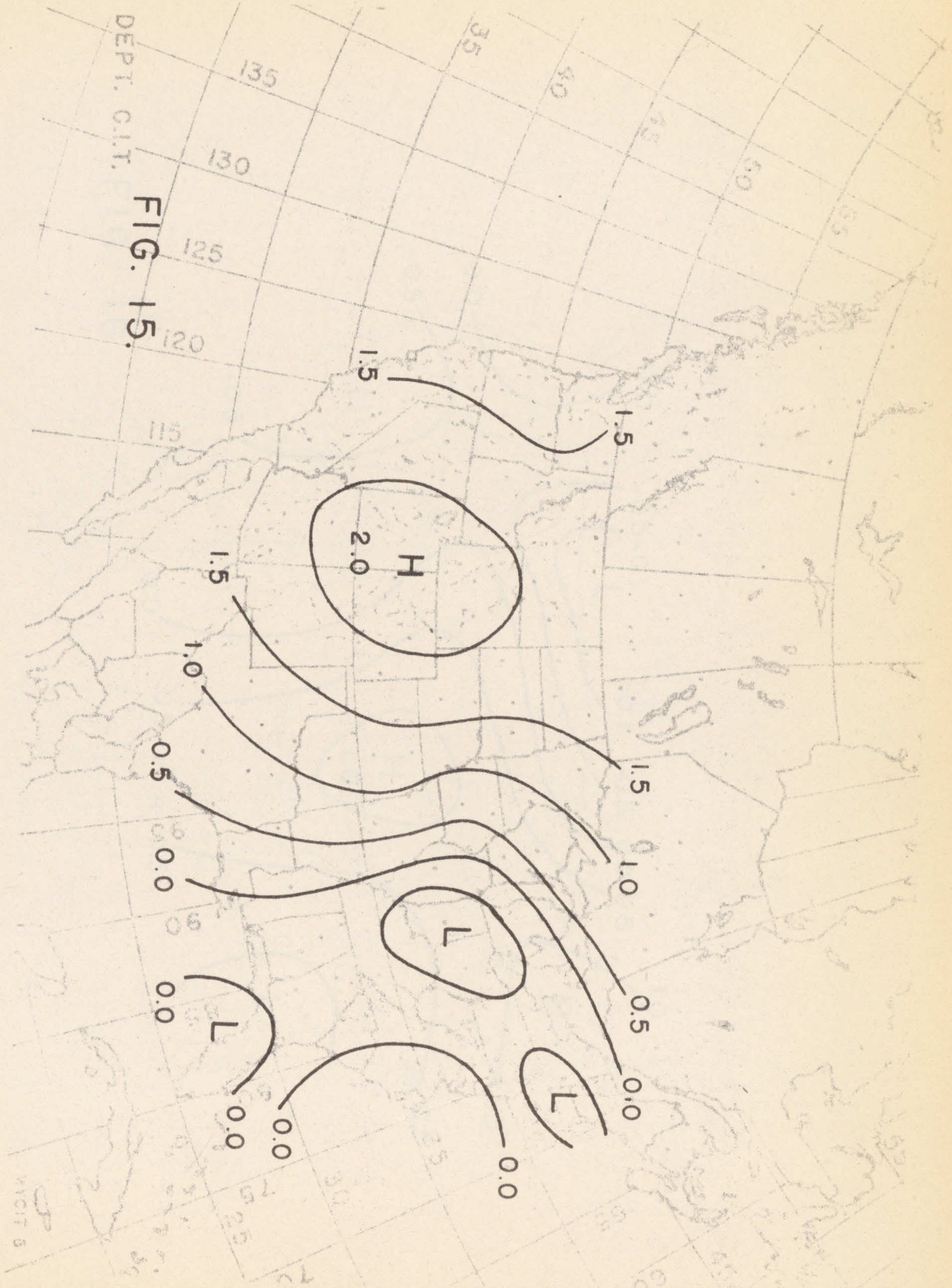
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FIG. 15.

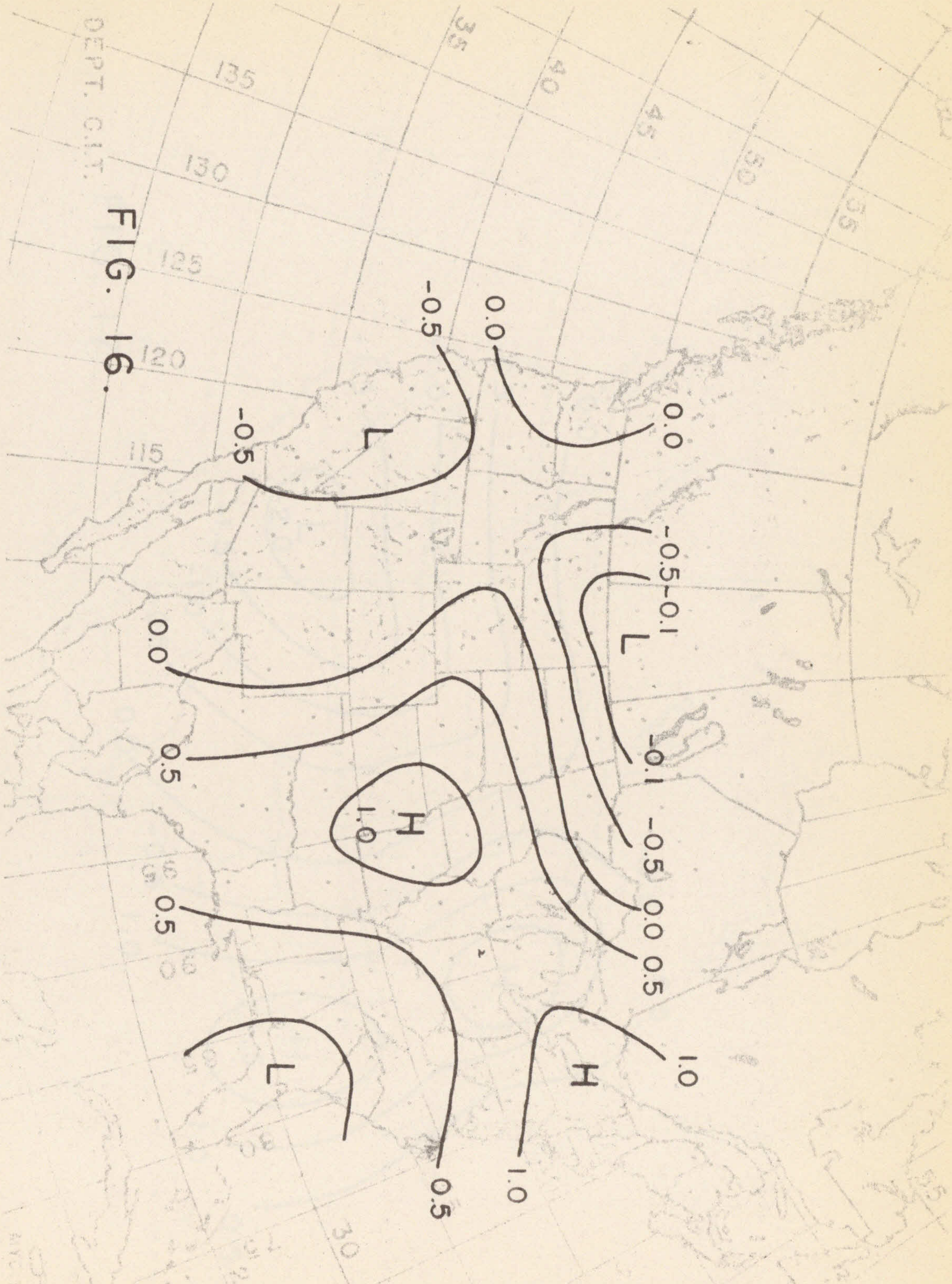
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FIG. 16.

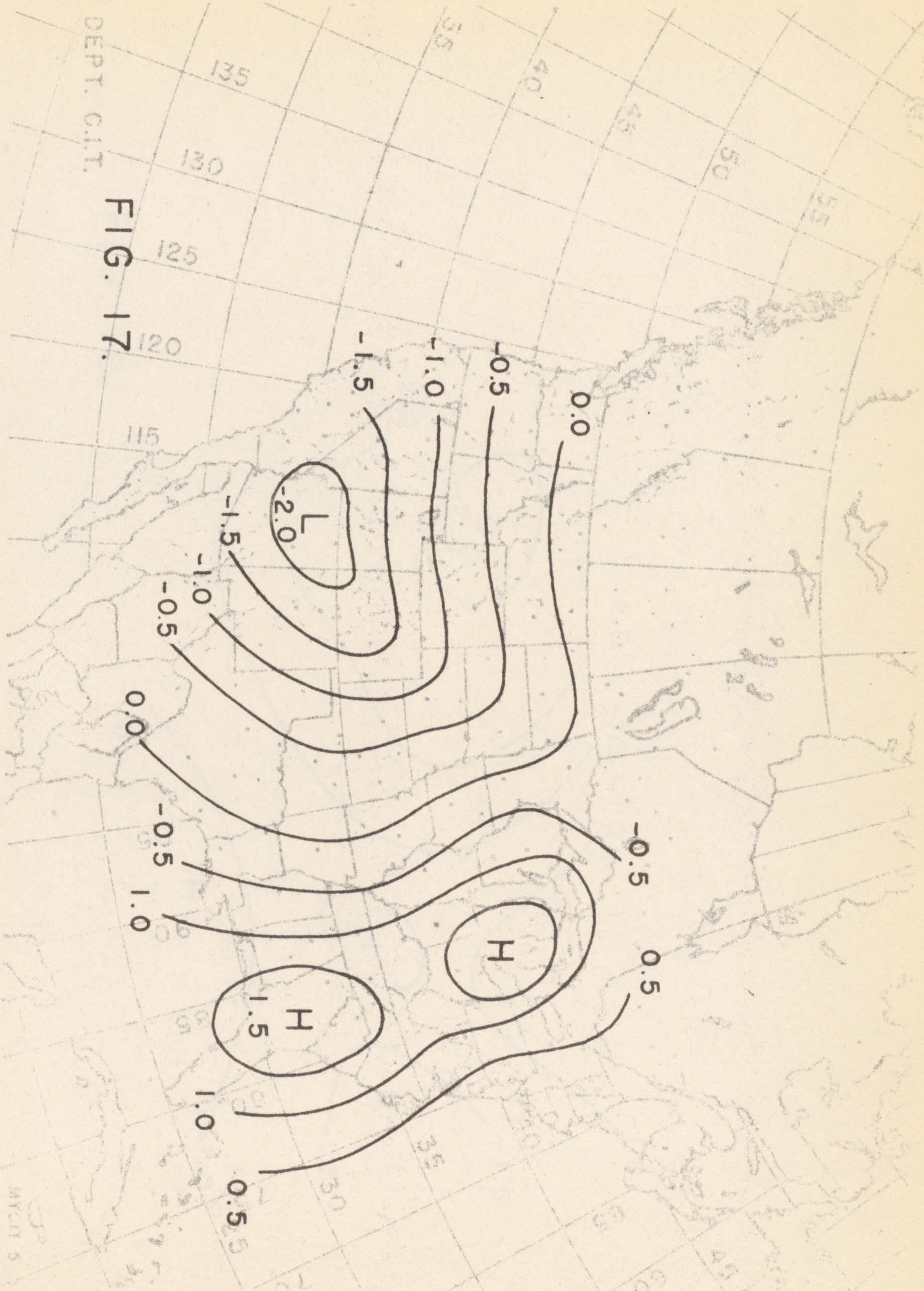


FIG. 17.

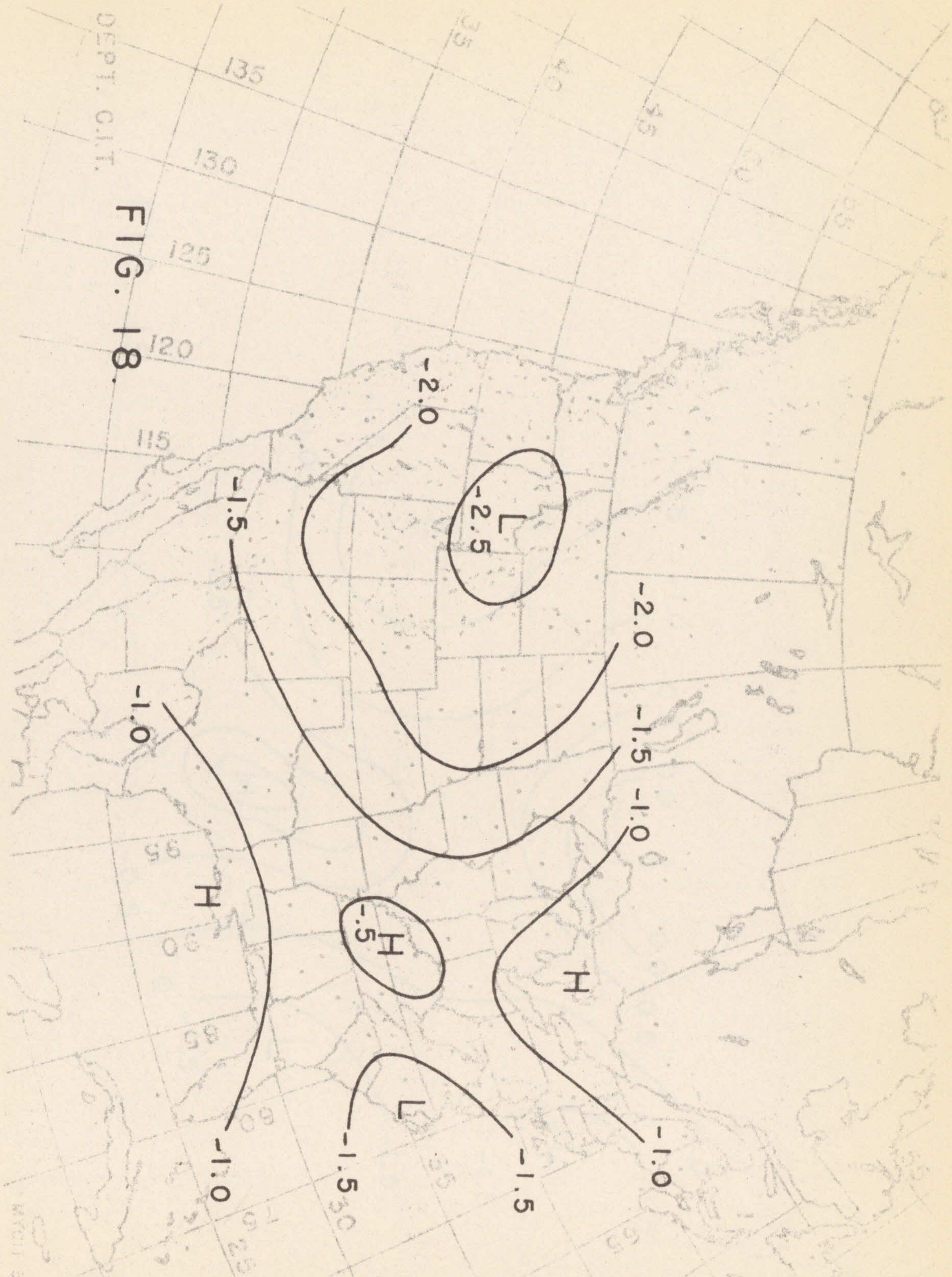


FIG. 18.

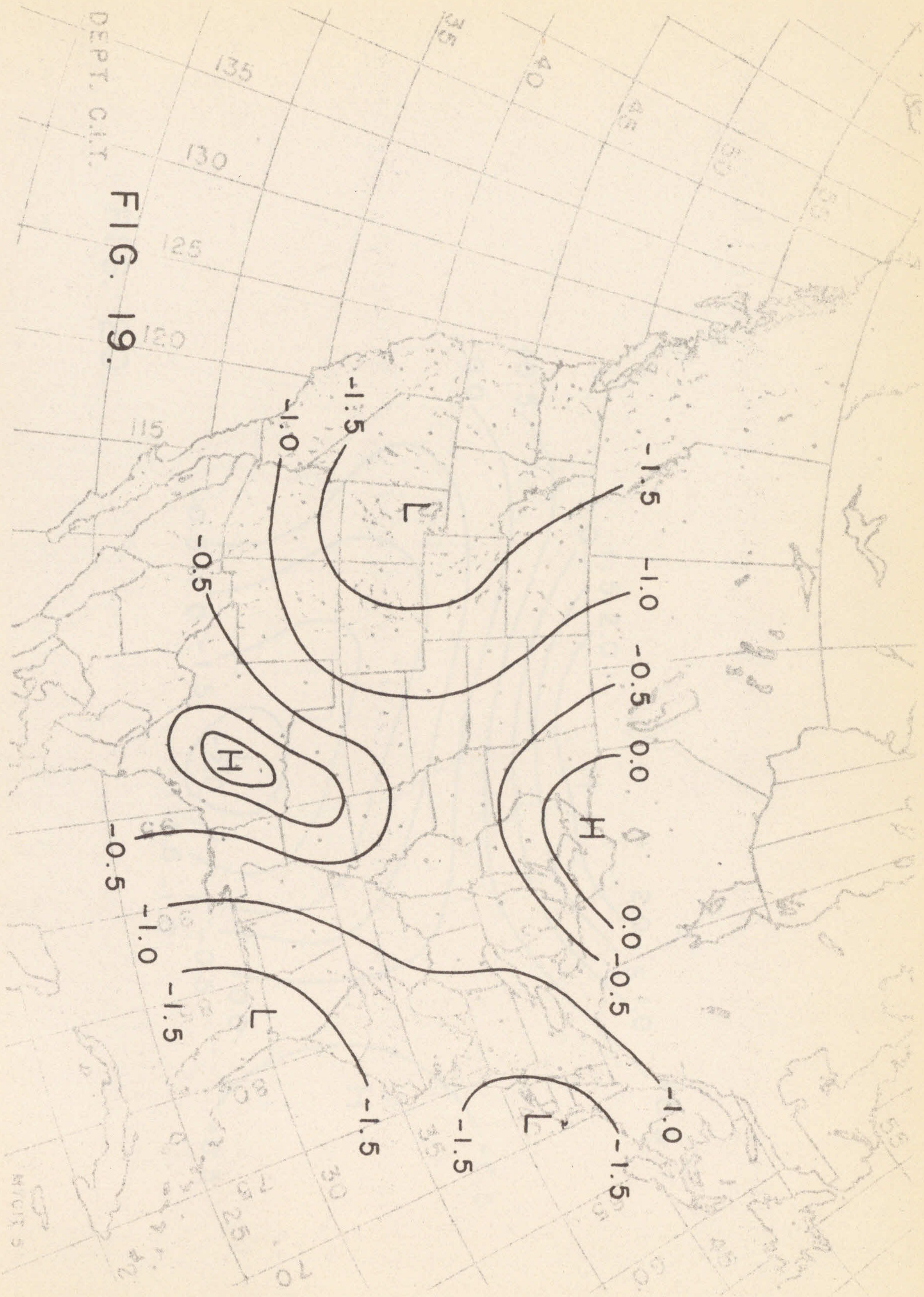


FIG. 19.

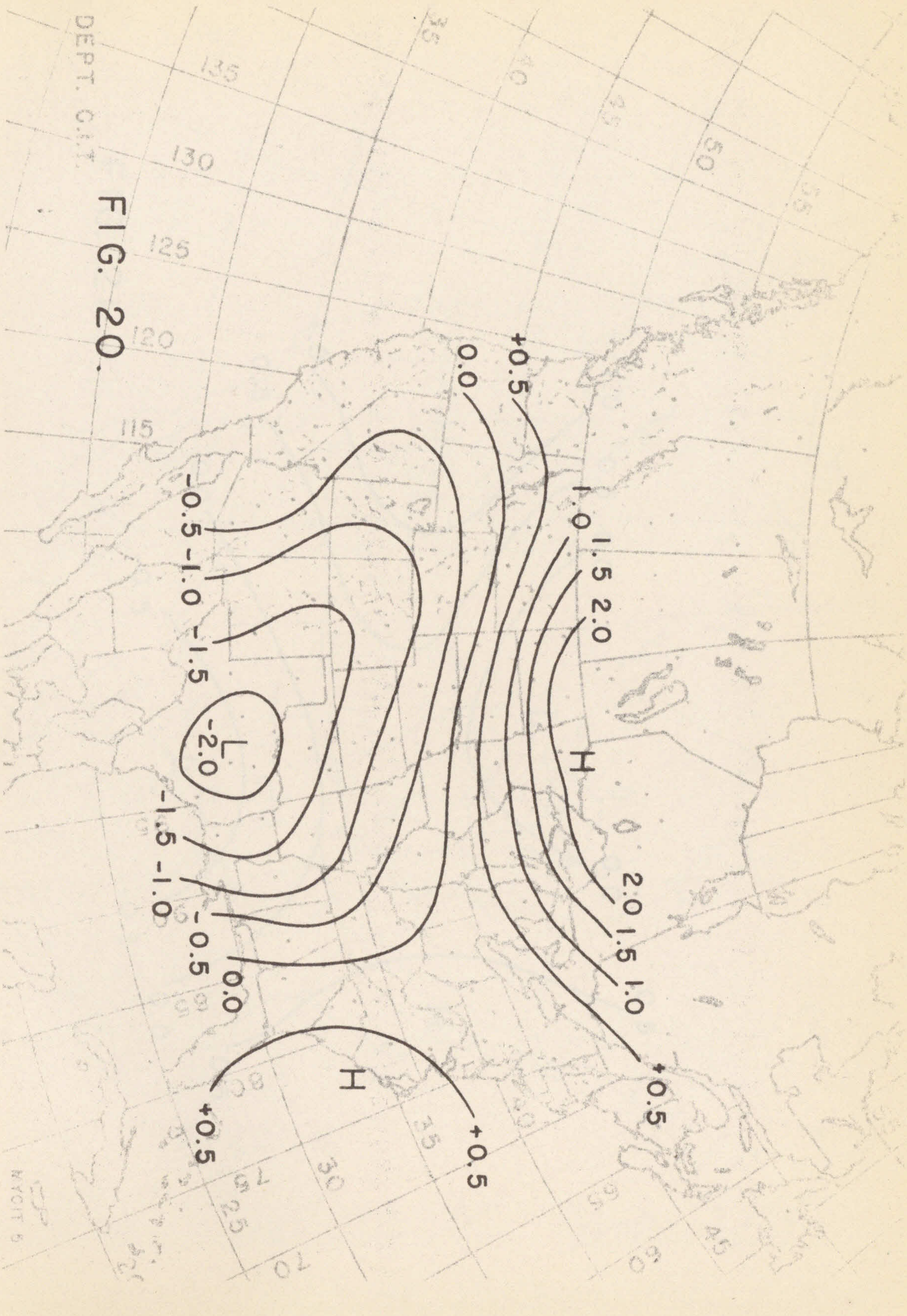


FIG. 20.

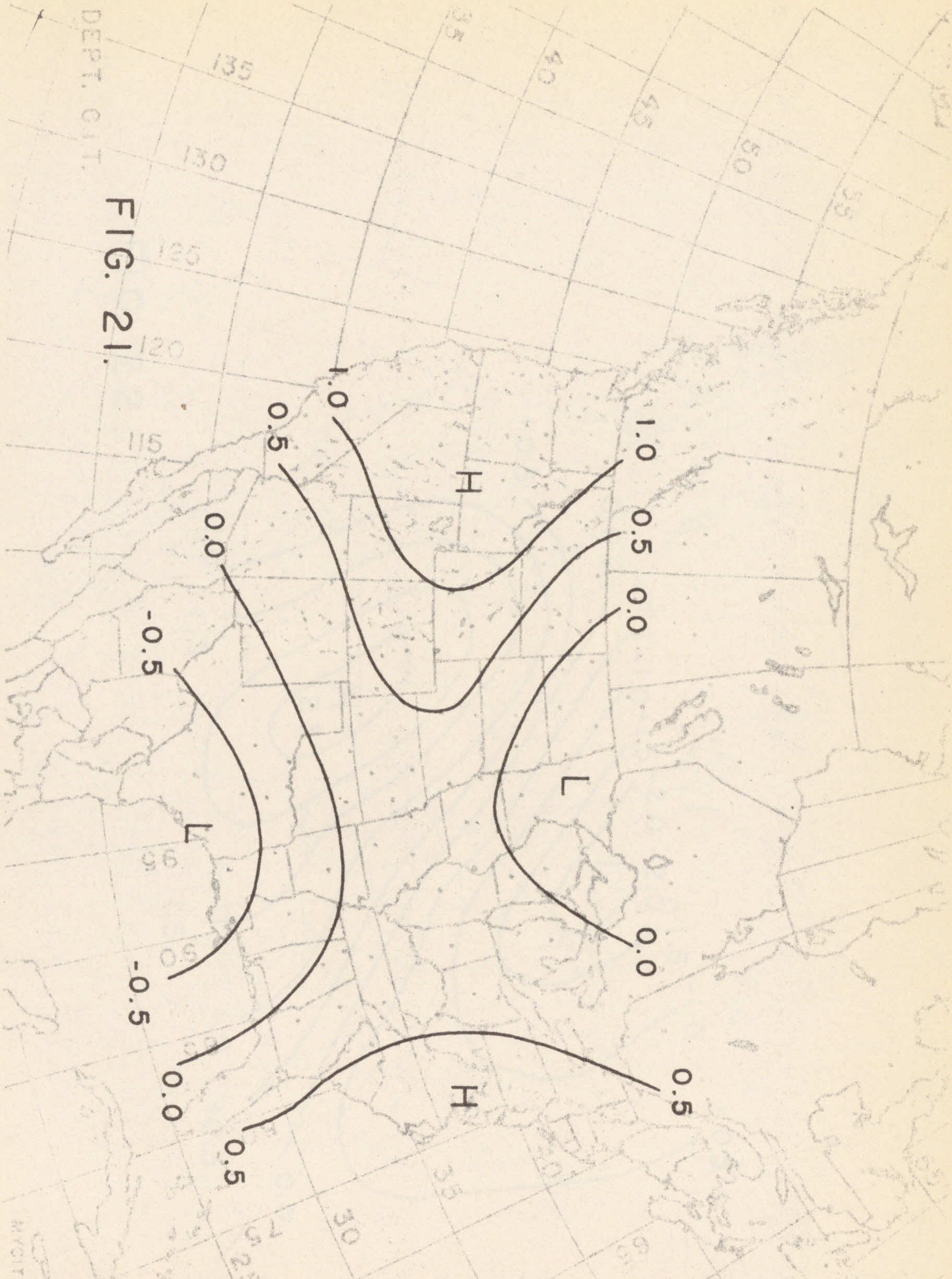


FIG. 21.

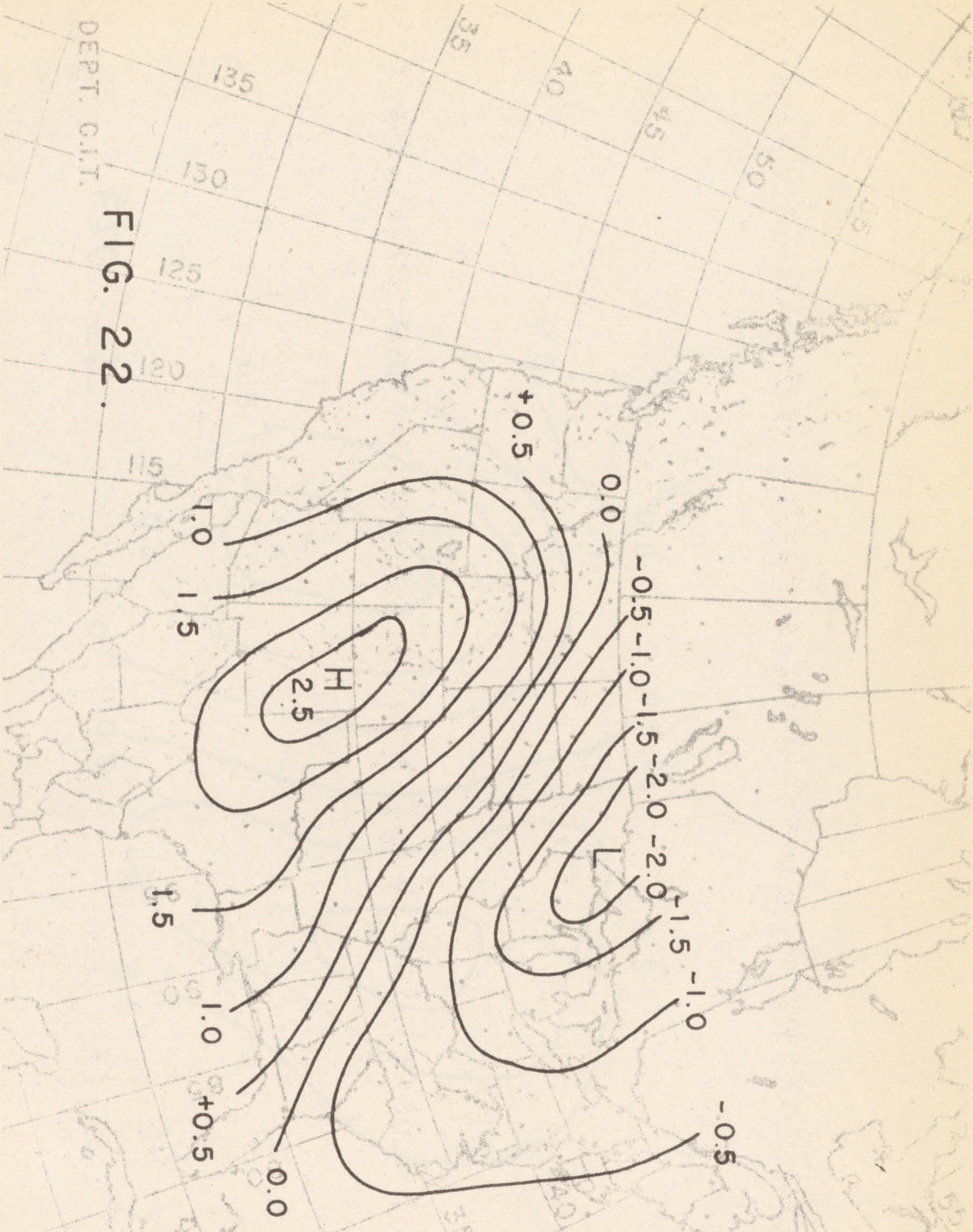


FIG. 22.

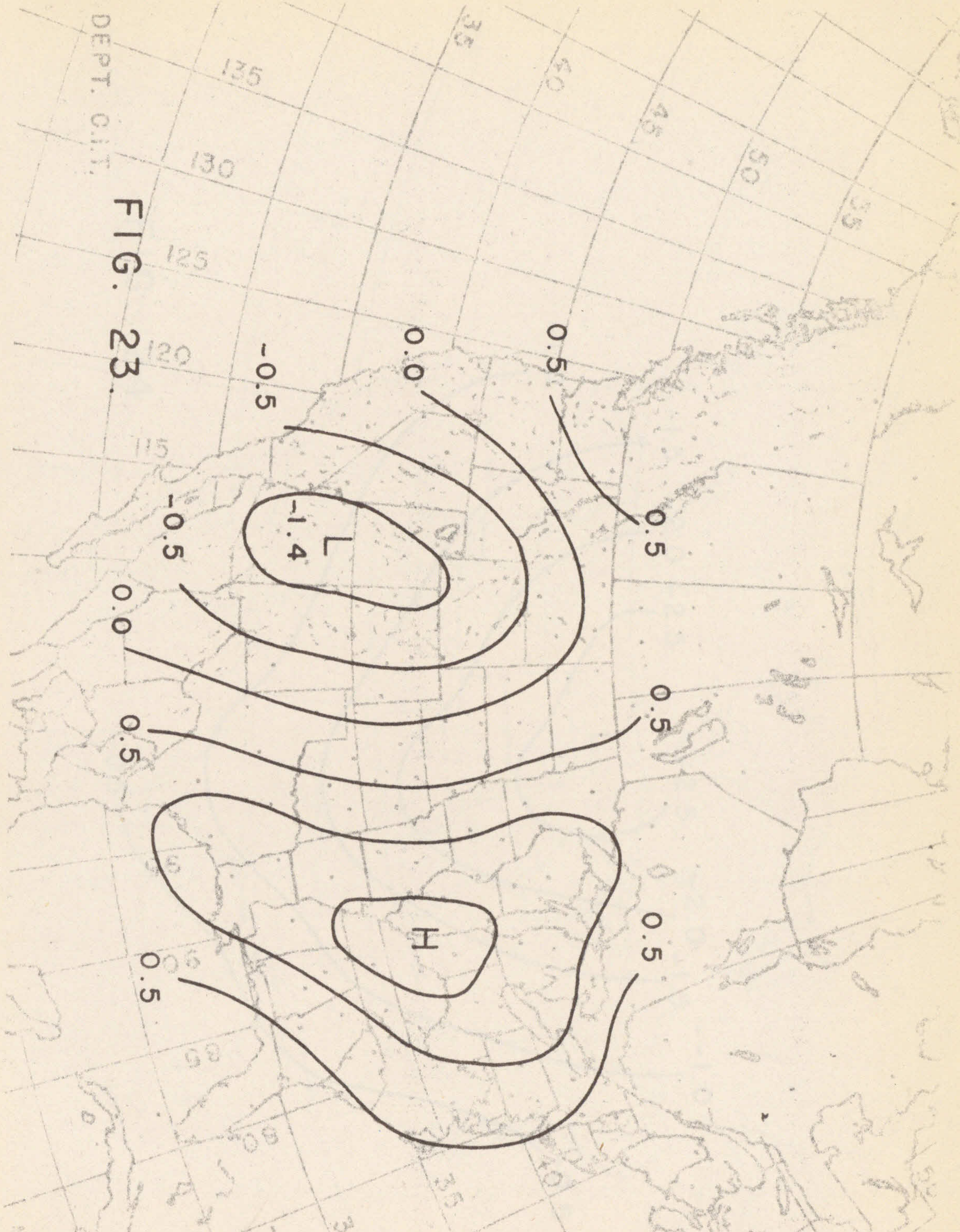

DEPT. C.I.T.
135
130
125
120
115
35
40
45
50
55
0.5
0.0
-0.5
-0.5
0.0
0.5
0.5
0.5
0.5
0.5
L
-1.4
H

FIG. 23.

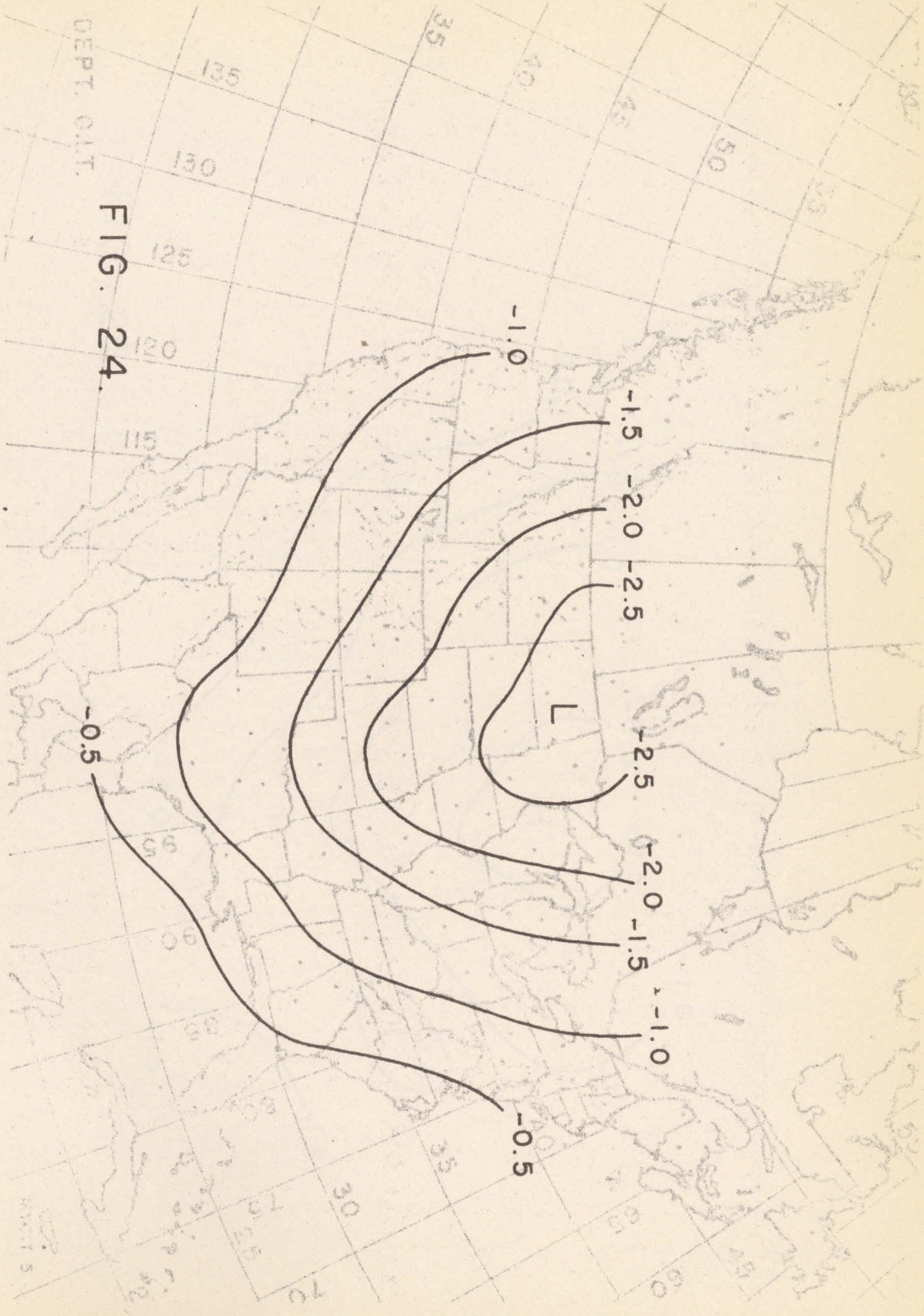


FIG. 24.

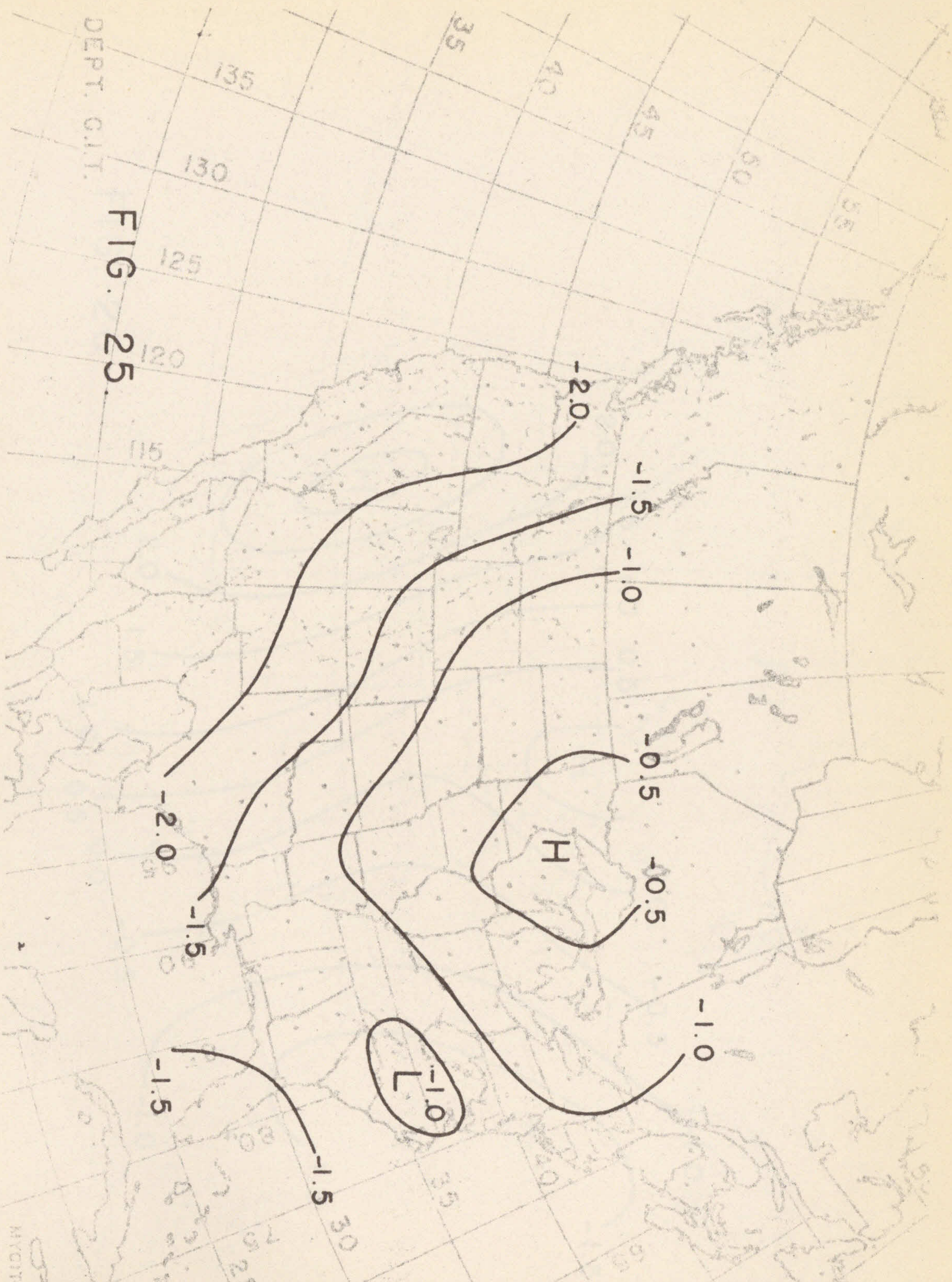


FIG. 25.

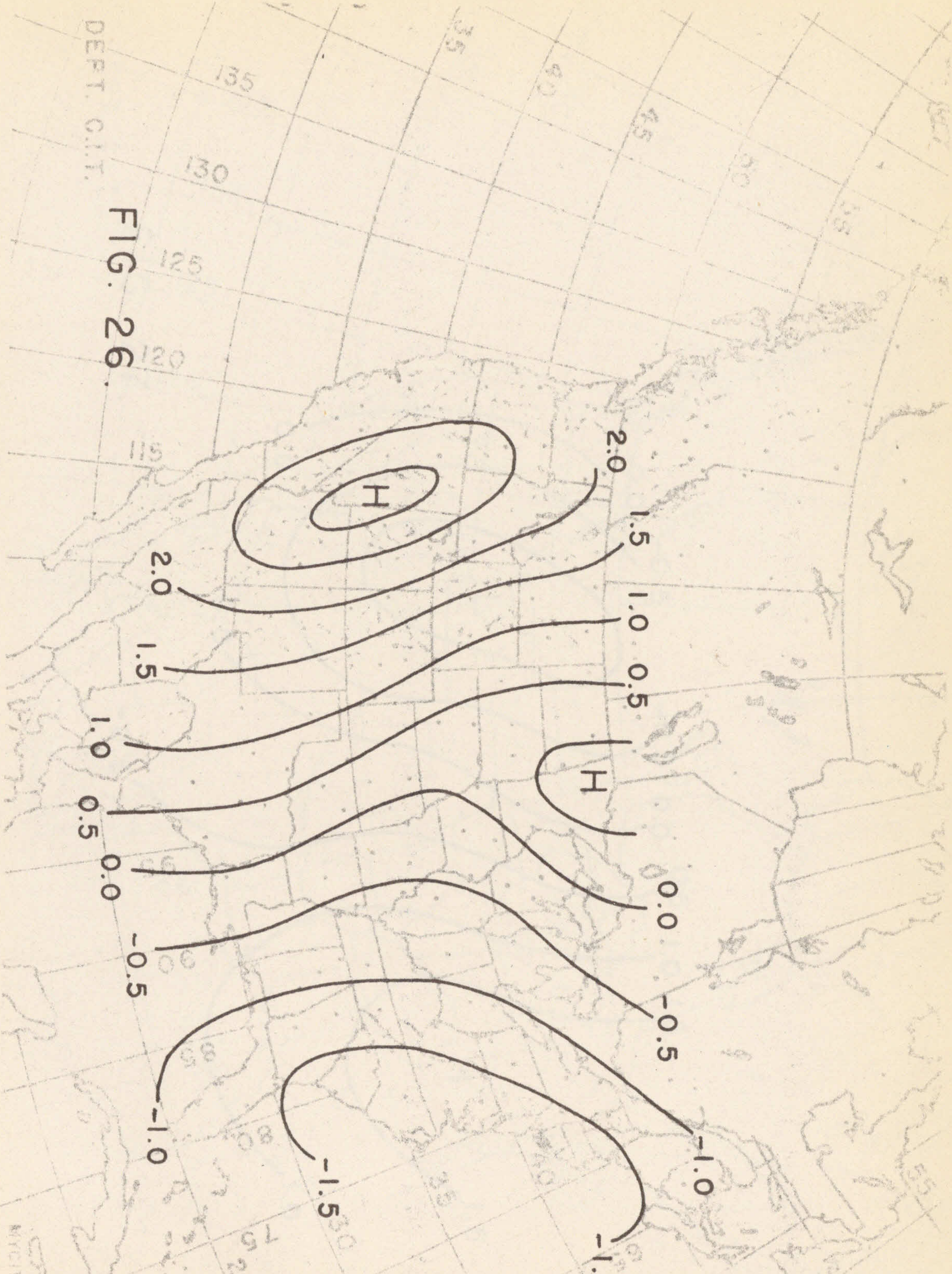


FIG. 26.

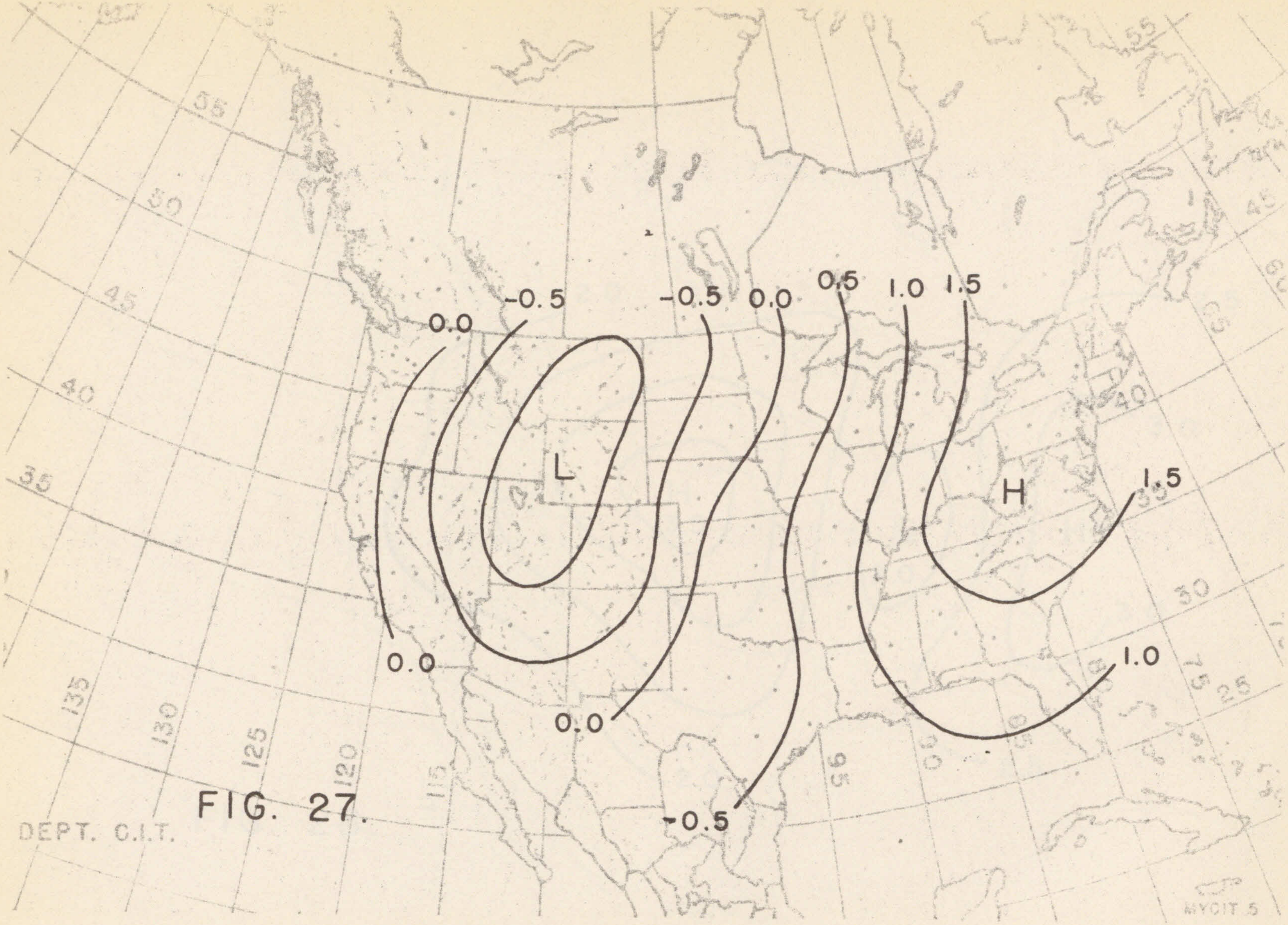


FIG. 27.

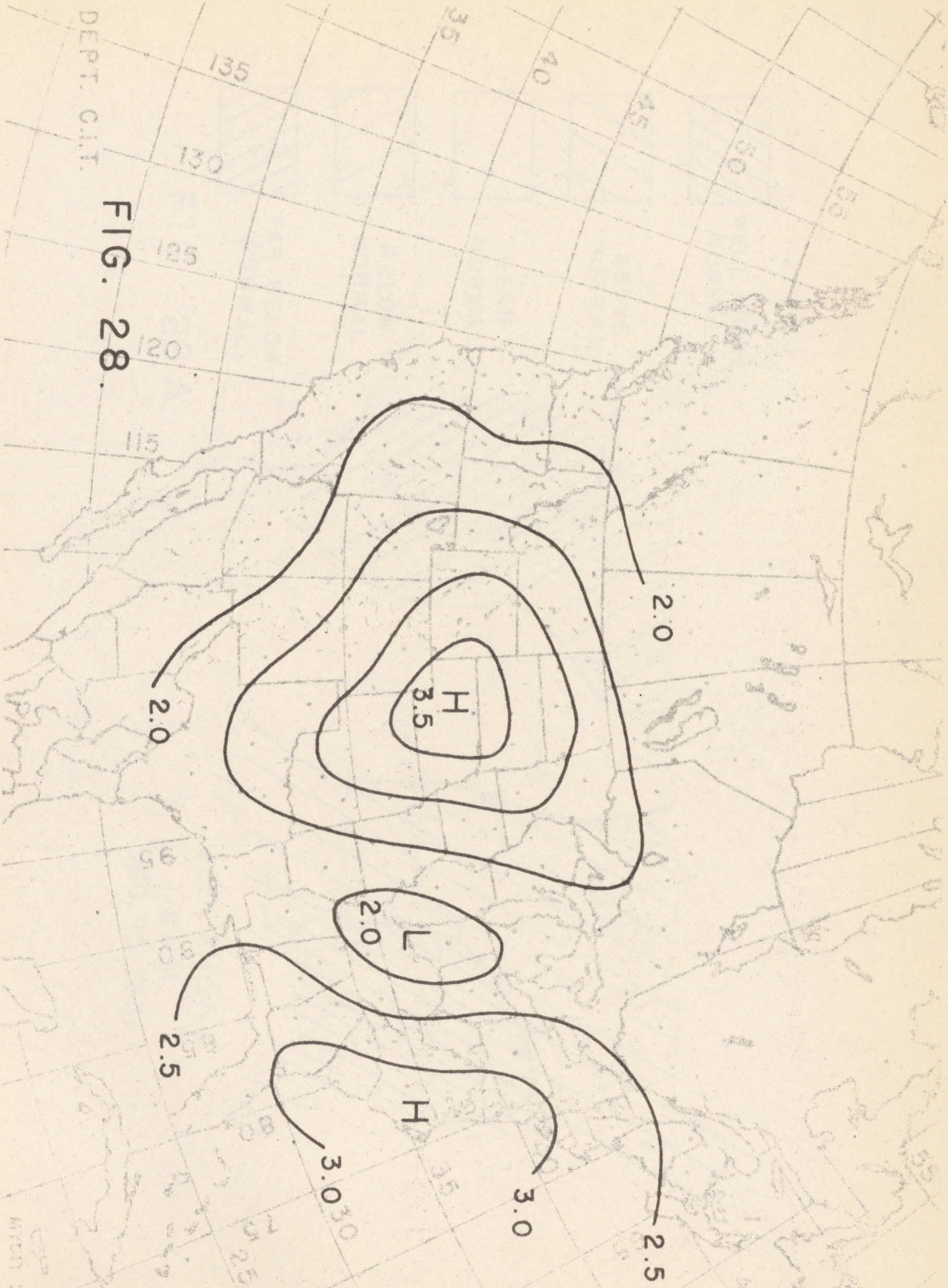


FIG. 28.

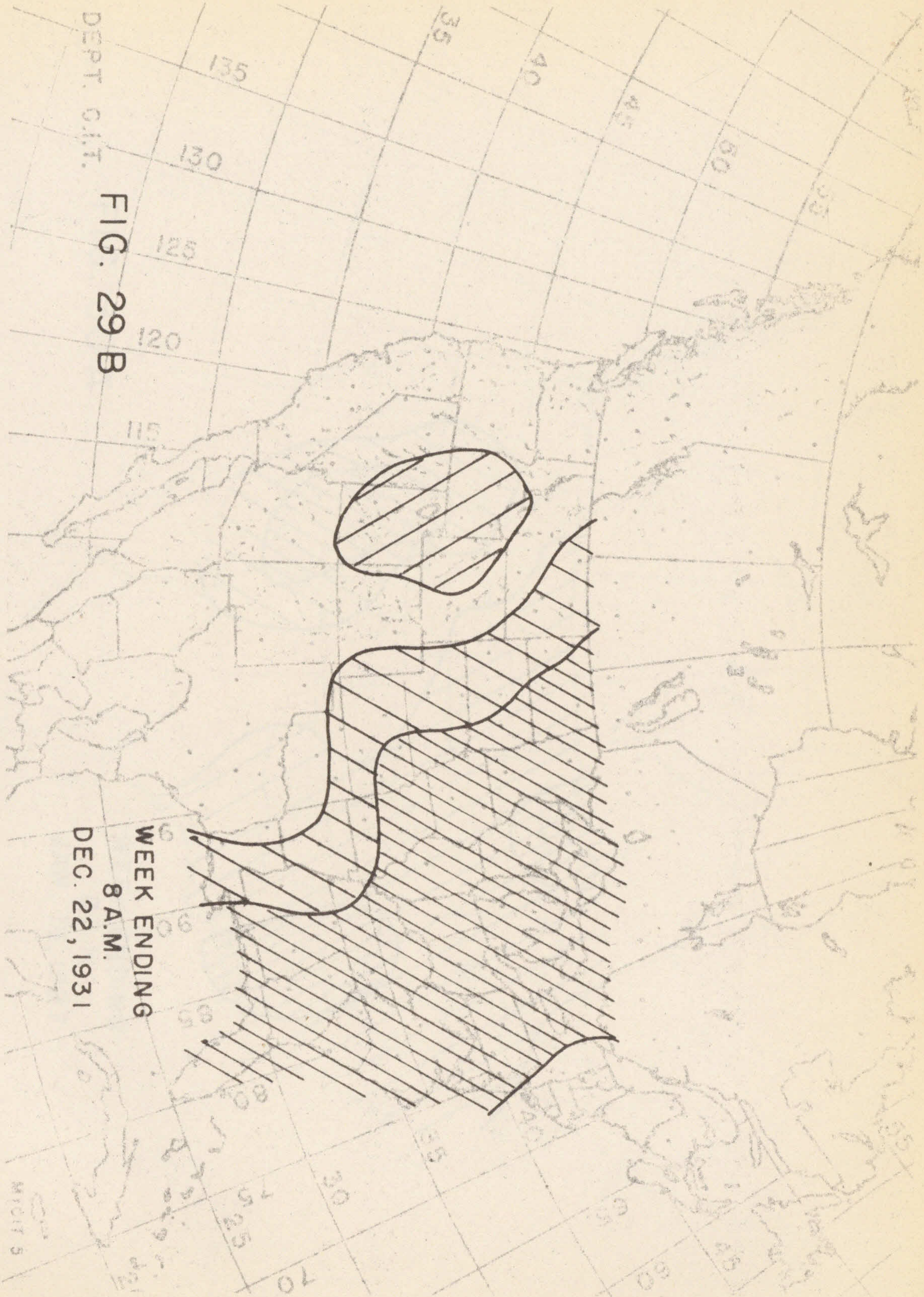


FIG. 29 B

WEEK ENDING
8 A.M.
DEC. 22, 1931

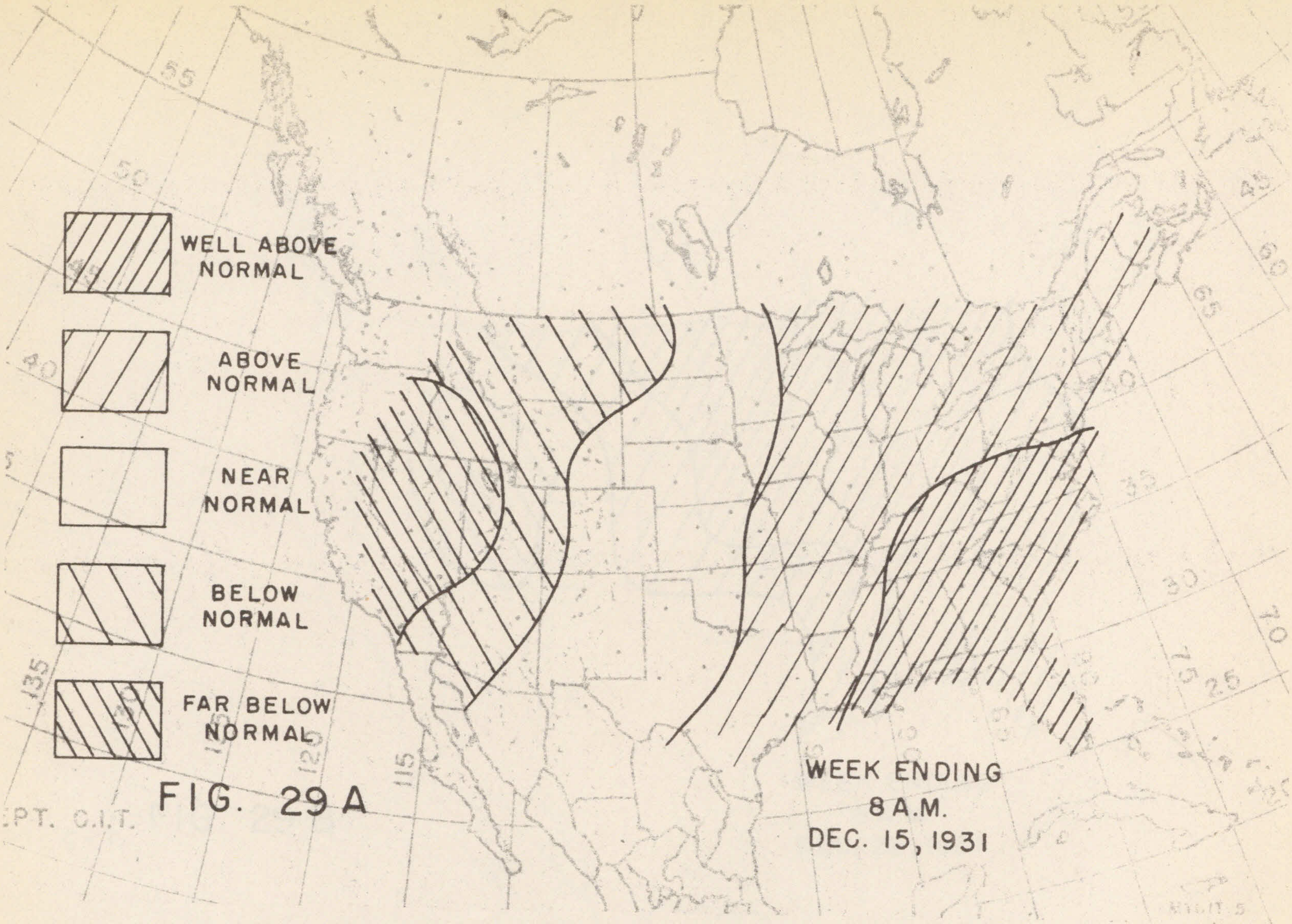

WELL ABOVE NORMAL
ABOVE NORMAL
NEAR NORMAL
BELOW NORMAL
FAR BELOW NORMAL
WEEK ENDING
8 A.M.
DEC. 15, 1931

FIG. 29 A

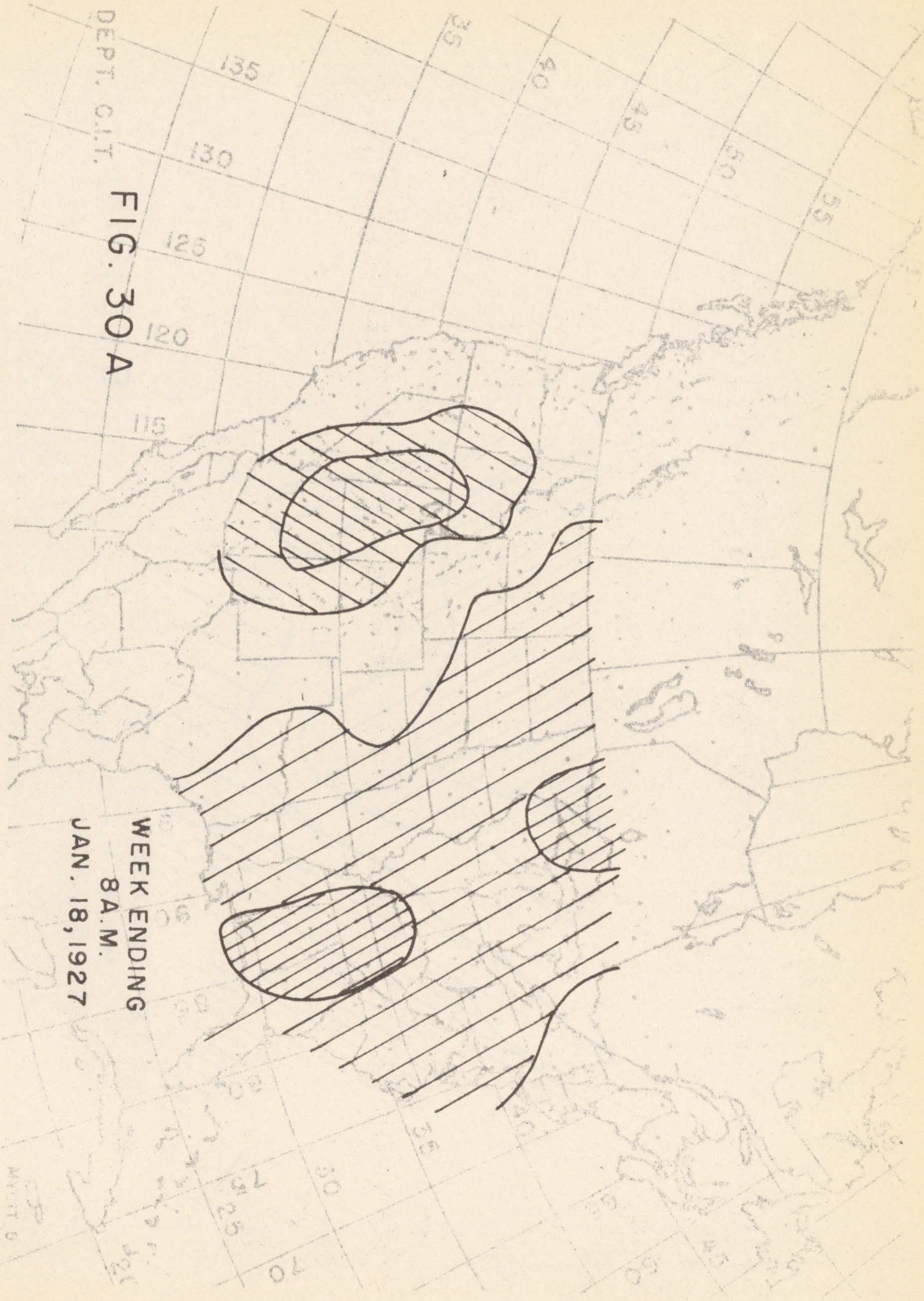
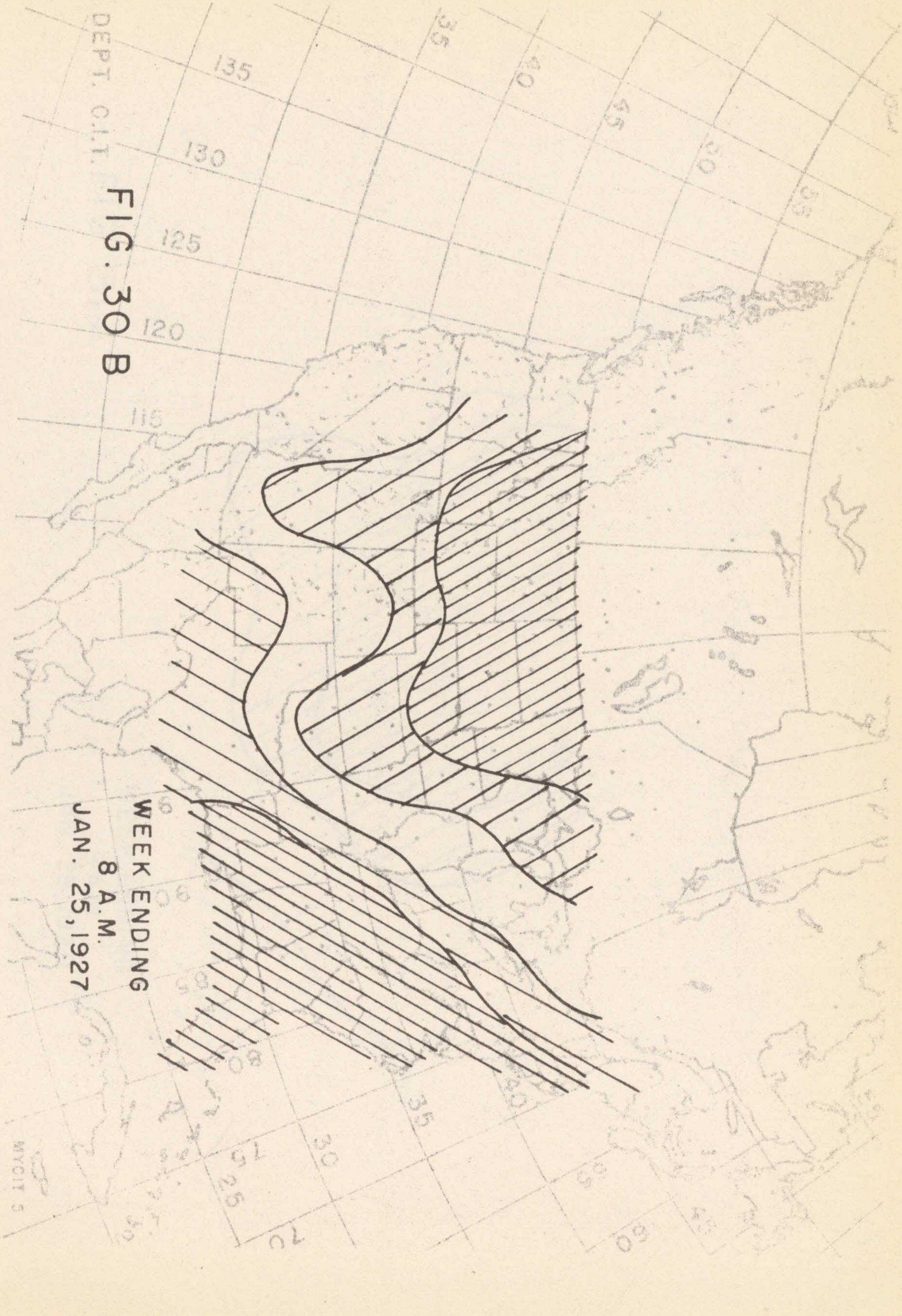
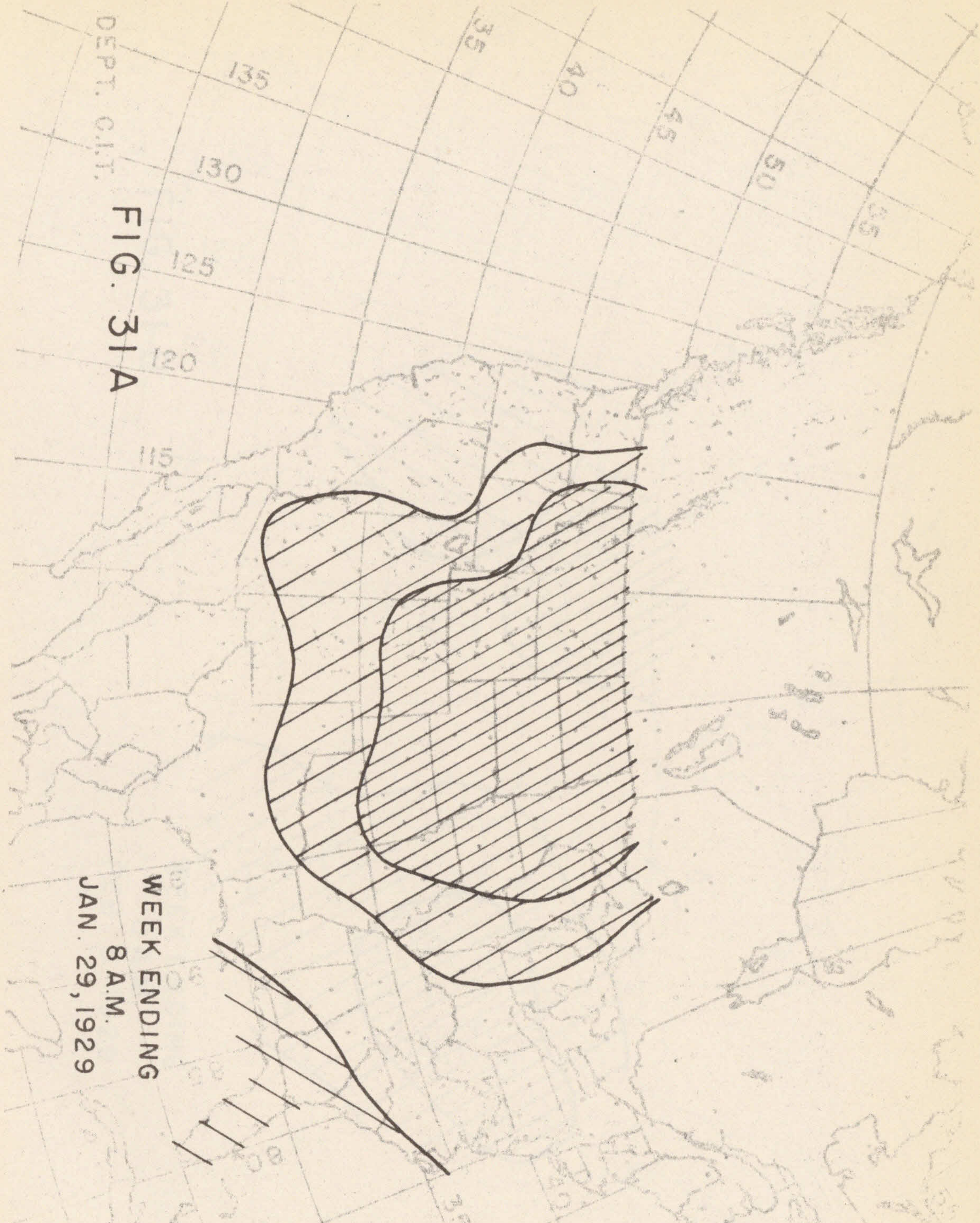

DEPT. C.I.T.
135
130
125
120
115
35
40
45
50
55
70
WEEK ENDING
8 A.M.
JAN. 18, 1927

FIG. 30 A


DEPT. C.I.T.
FIG. 30 B
WEEK ENDING
8 A.M.
JAN. 25,1927


DEPT. C.I.T.
FIG. 31A
WEEK ENDING
8 A.M.
JAN. 29, 1929

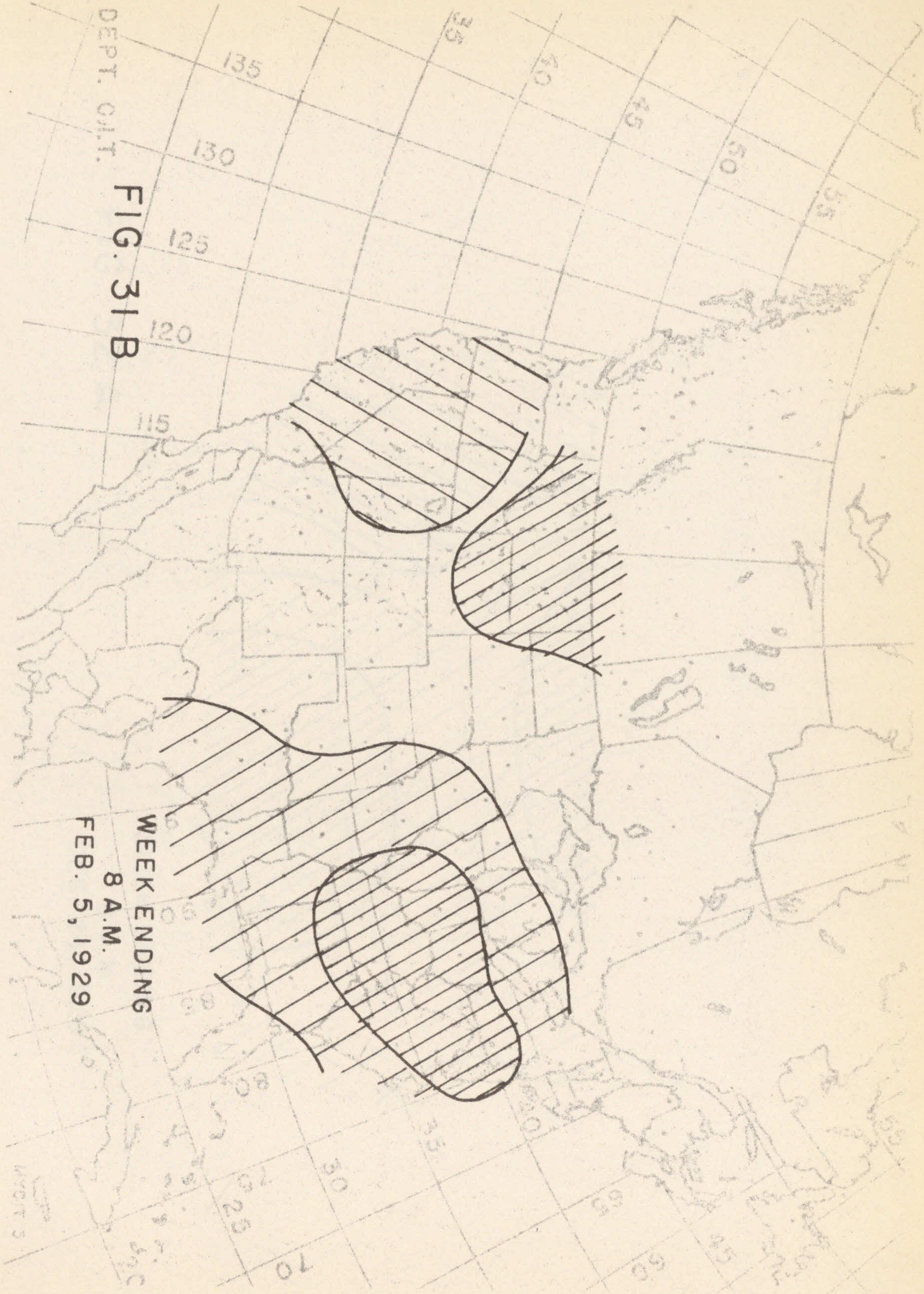


FIG. 31 B

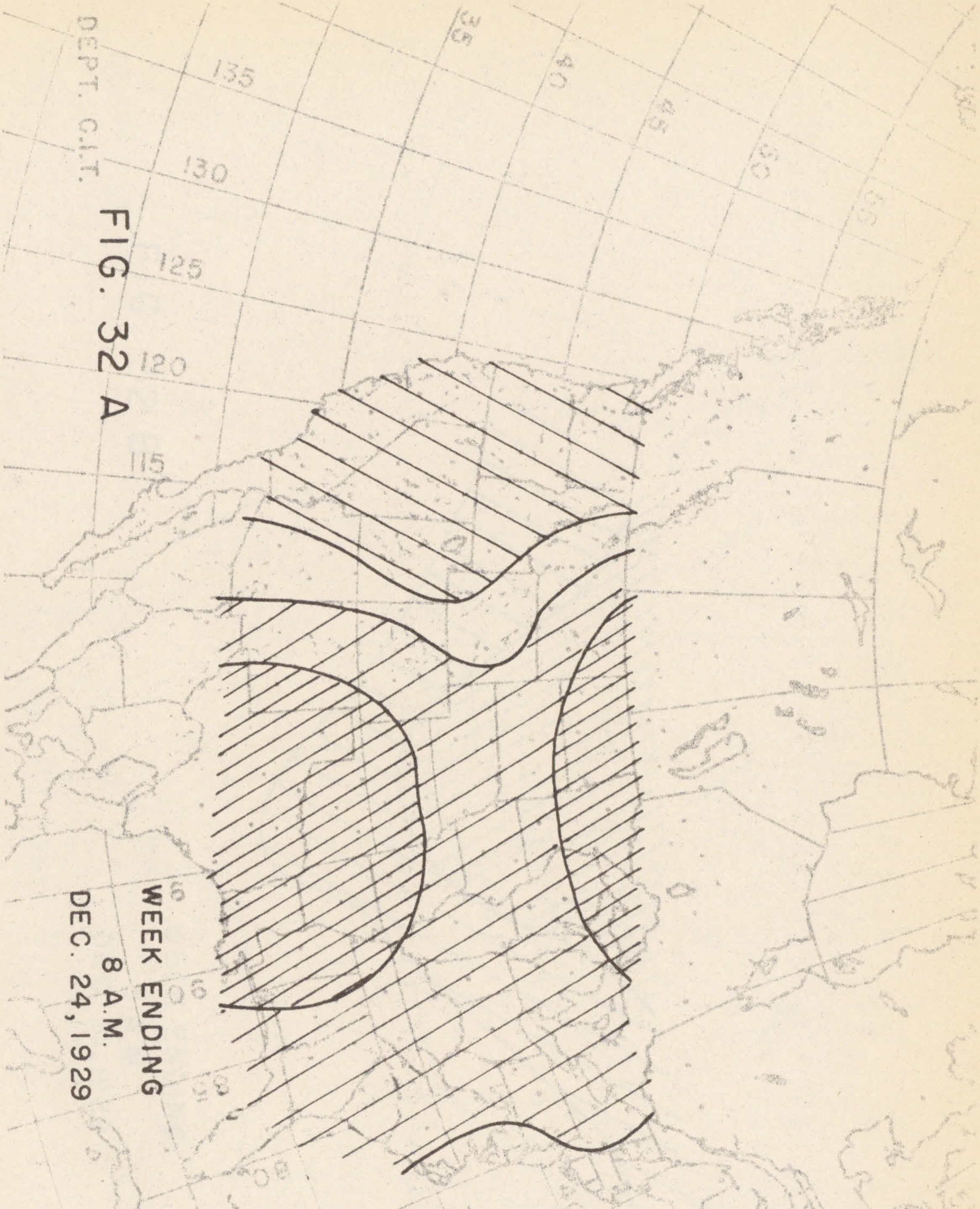


FIG. 32 A

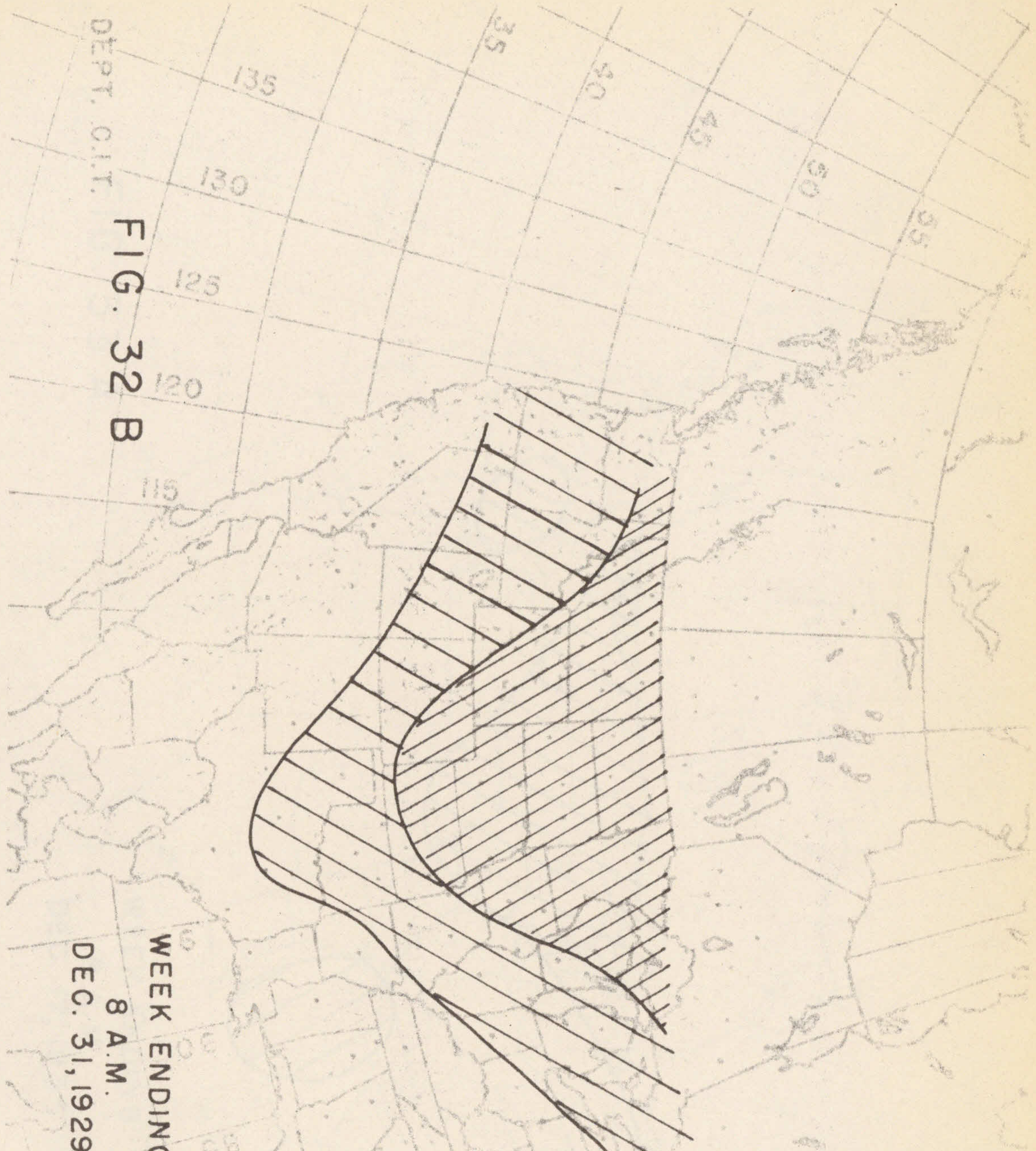


FIG. 32 B

WEEK ENDING
8 A.M.
DEC. 31, 1929

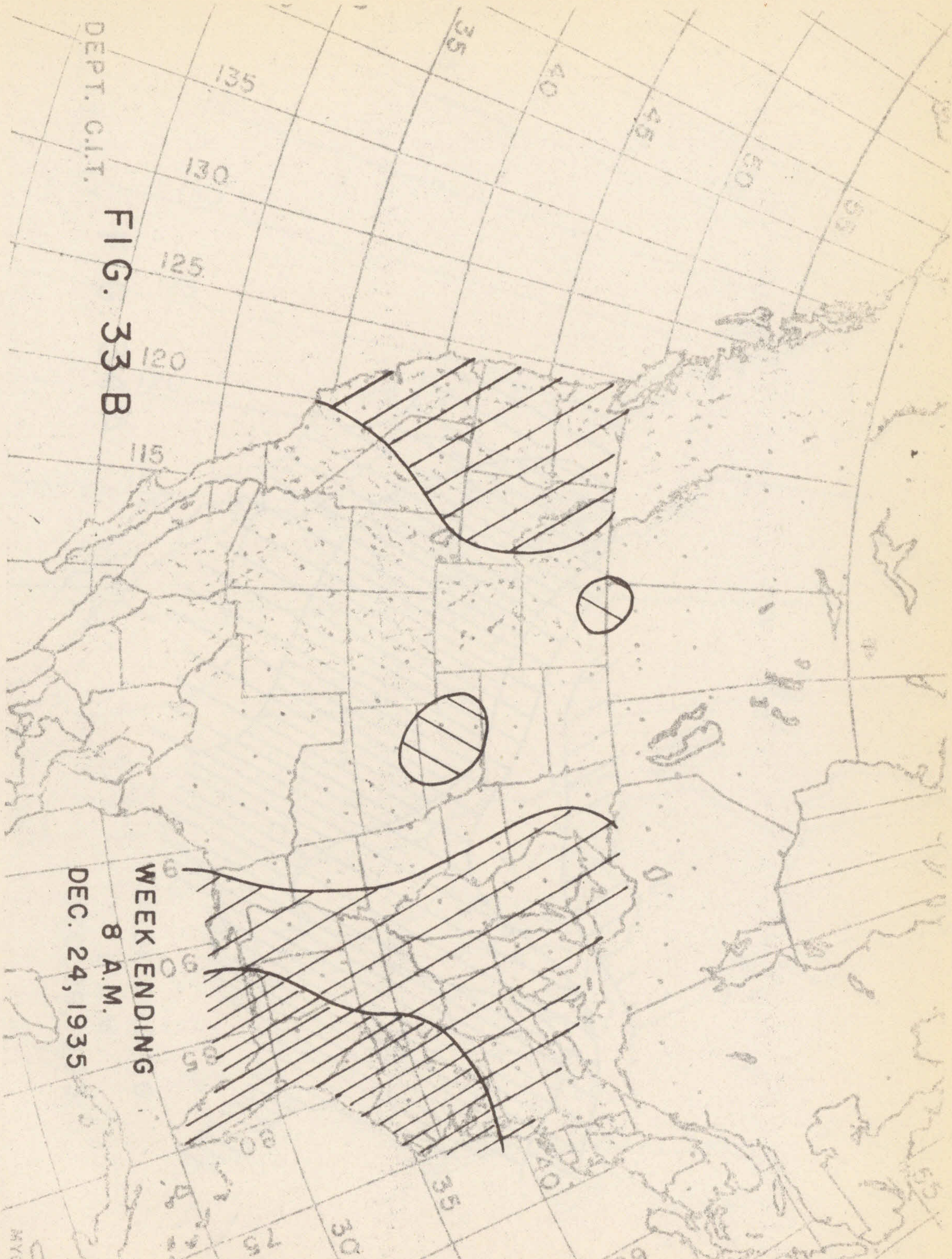


FIG. 33 B

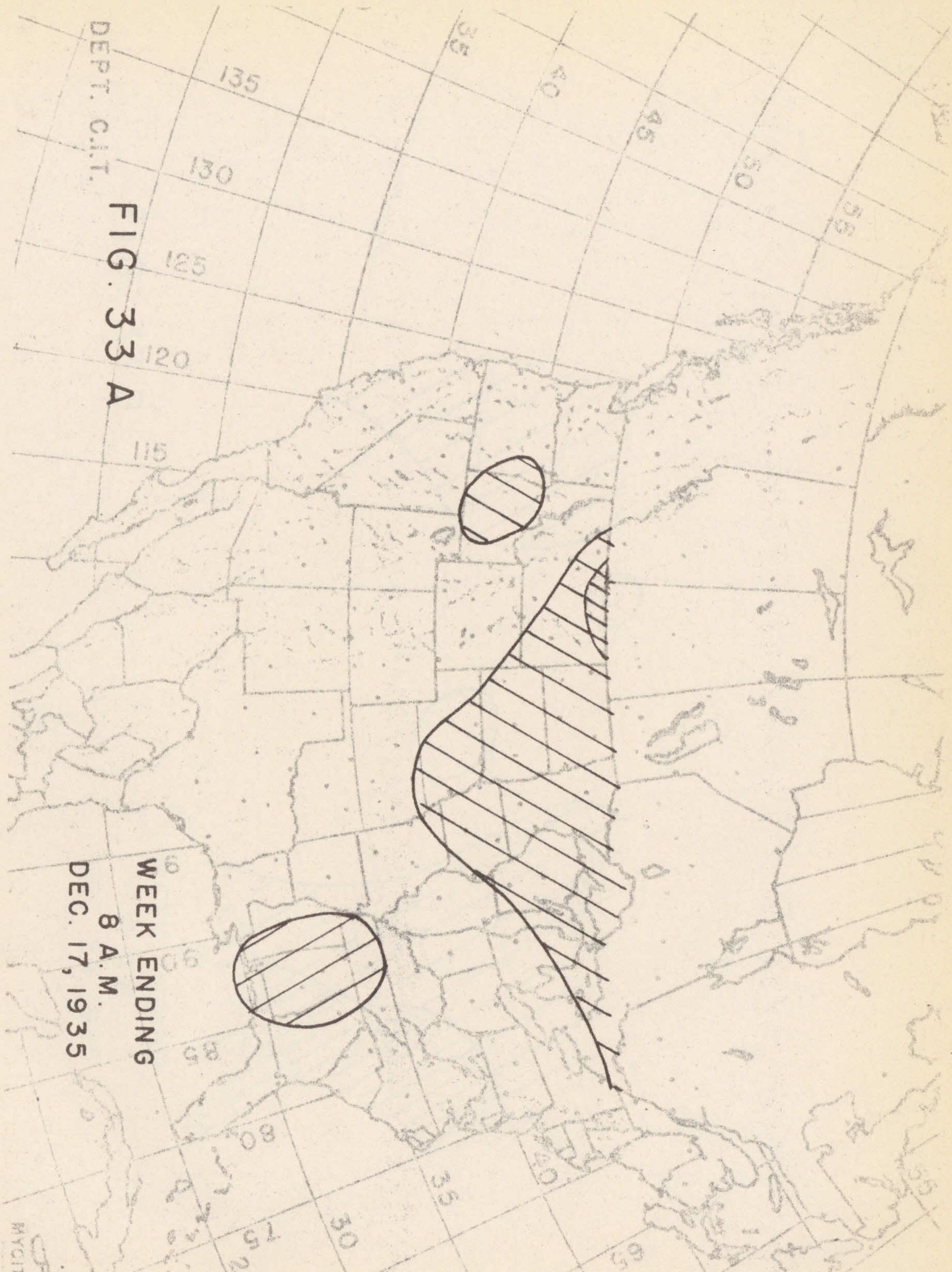


FIG. 33 A

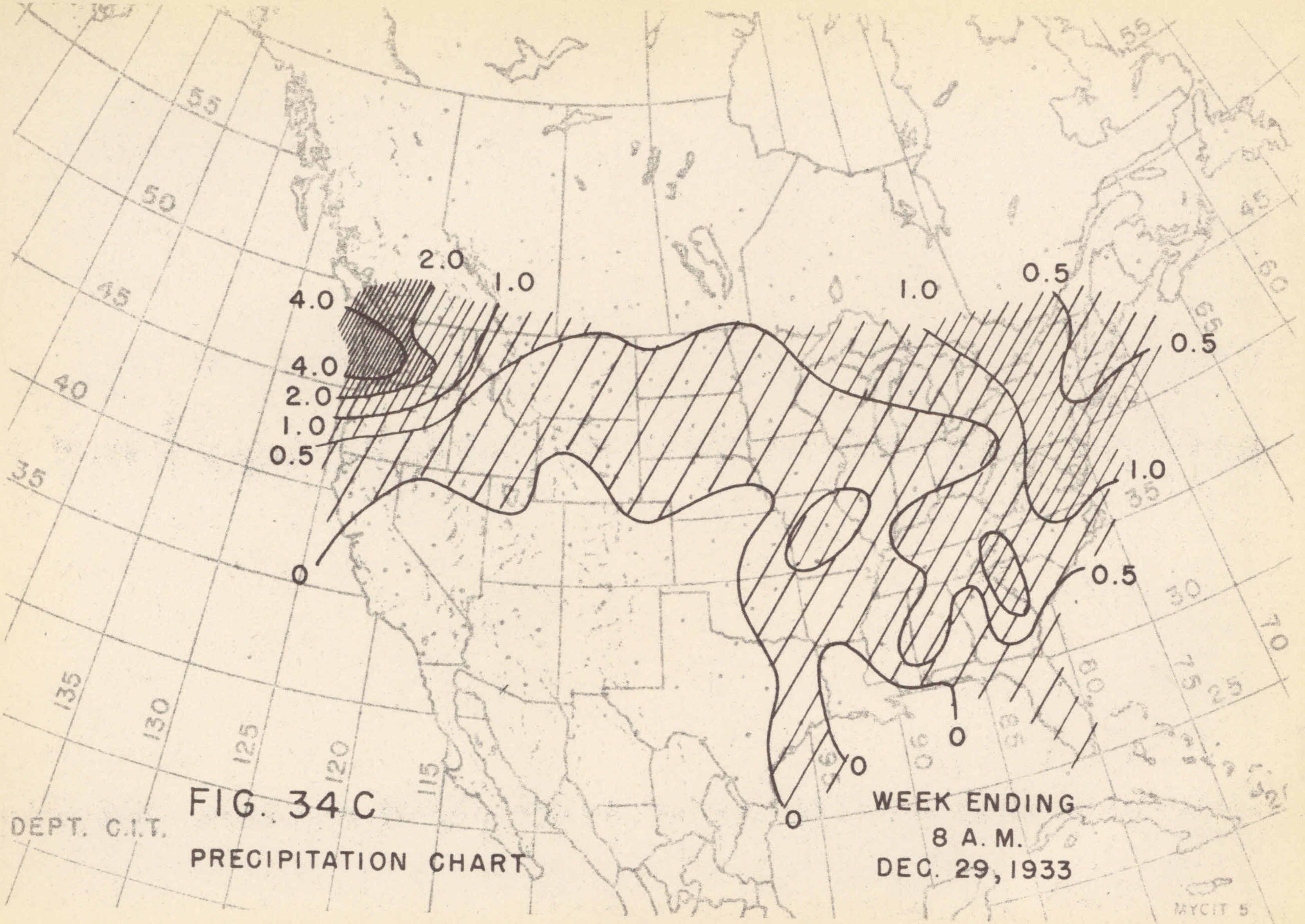


FIG. 34 C

PRECIPITATION CHART

WEEK ENDING
8 A.M.
DEC. 29, 1933

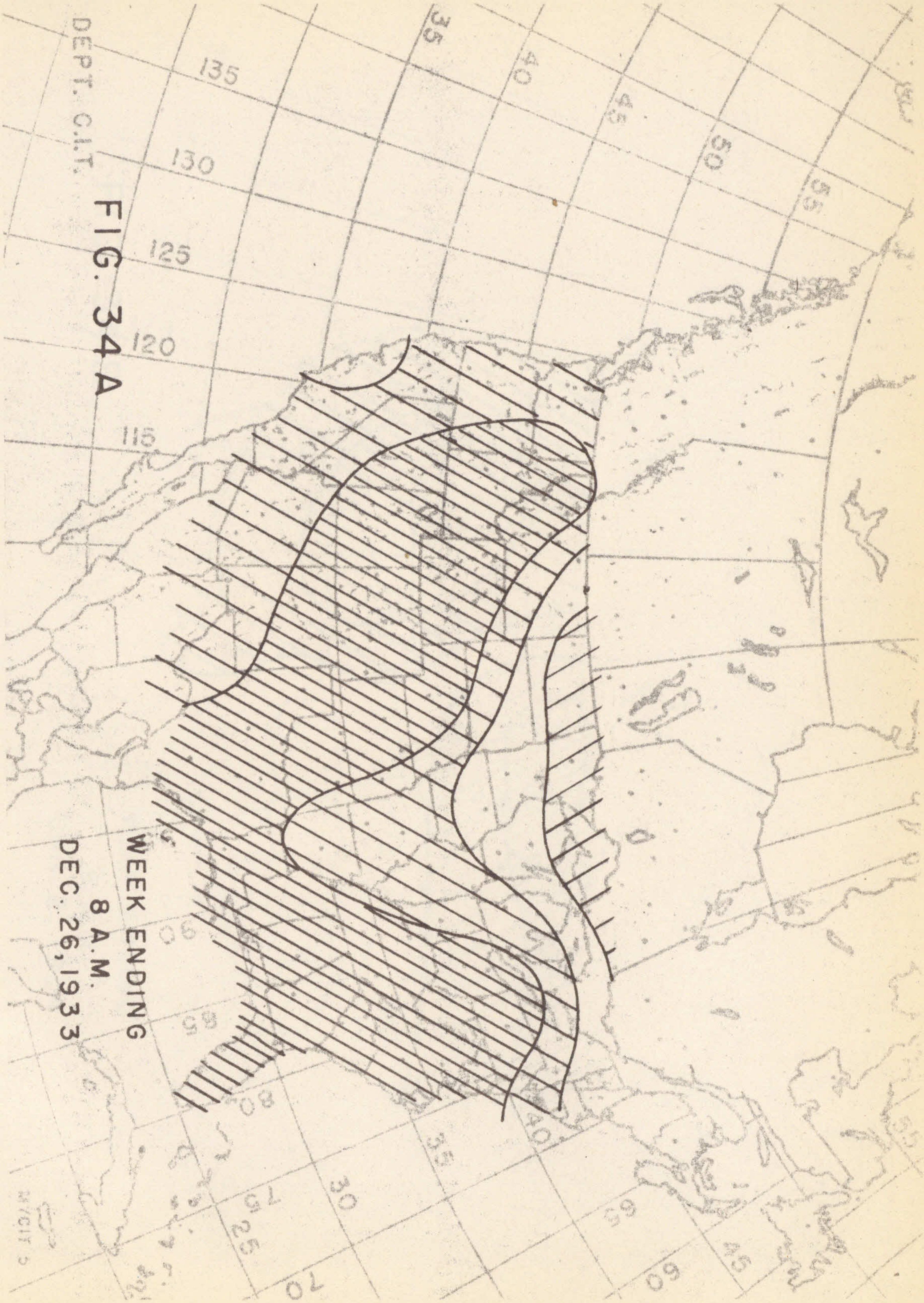


FIG. 34 A
DEPT. C.I.T.
WEEK ENDING
8 A.M.
DEC. 26, 1933

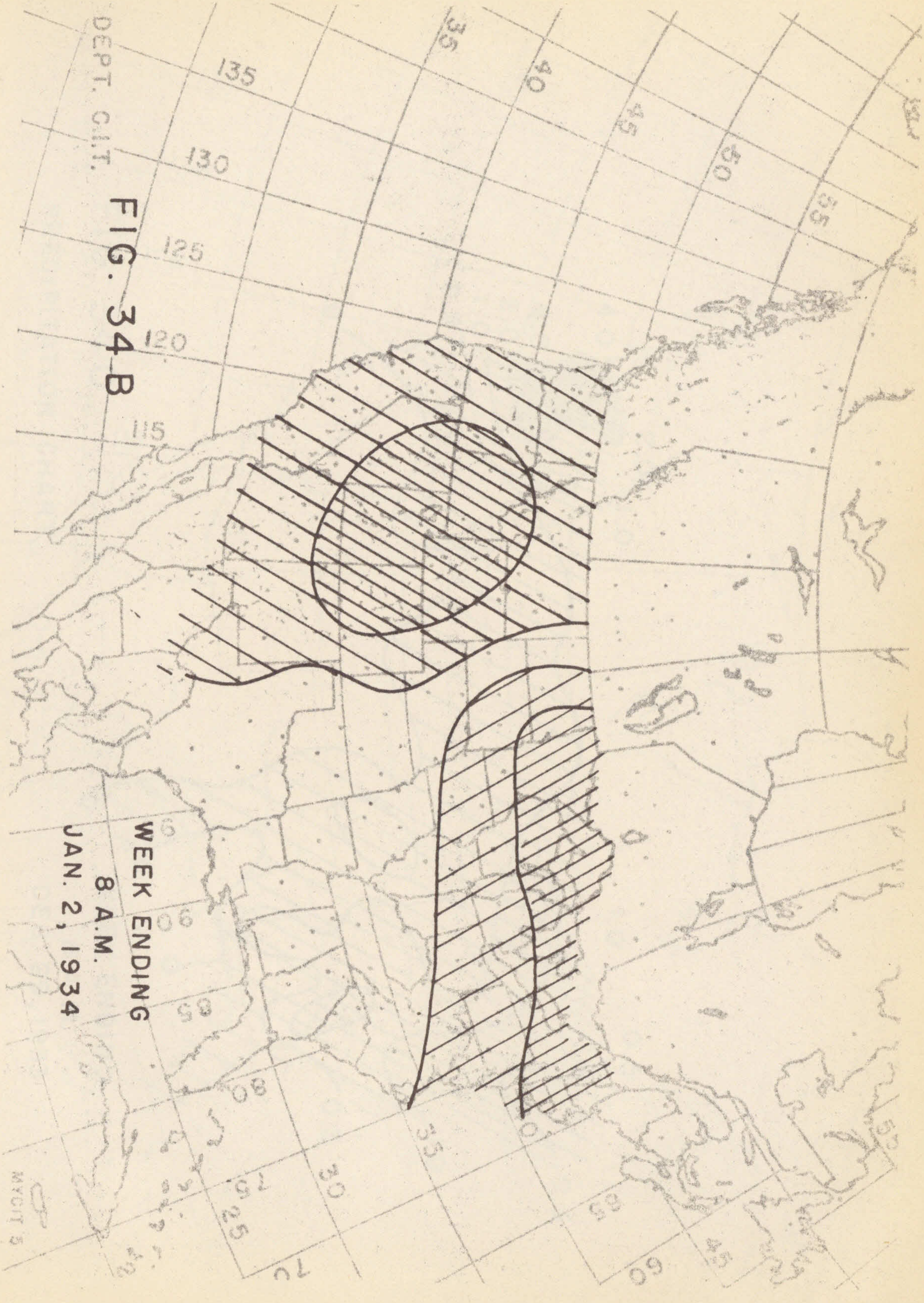


FIG. 34 B

WEEK ENDING
8 A.M.
JAN. 2, 1934